



## **Catalysing low cost green technologies for sustainable water service delivery in Kenya: Feasibility Study Report**

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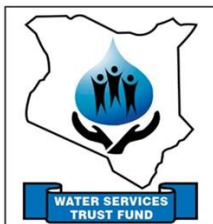


**CTCN**  
CLIMATE TECHNOLOGY  
CENTRE & NETWORK



# Catalysing low cost green technologies for sustainable water service delivery in Kenya

## Feasibility Study Report



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## Acknowledgements

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This report was prepared for the Climate Technology Centre Network (CTCN) by Wangai Ndirangu, from Batiment Engineering and Associates (BEA) Kenya, and Caroline Schaer from UNEP DTU Partnership (UDP) Denmark, with assistance from Esther Ng'ang'a from BEA. The study was made possible with guidance from Water Services Trust Fund (WSTF) and Kenya Industrial Research and Development Institute (KIRDI), the Designated National Entity for CTCN in Kenya.

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## Terms and Abbreviations

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Term/Abbreviation	Meaning
ACTS	African Centre for Technology Studies
ASALs	Arid and semi-arid areas
CBOs	Community Based Organization
CoK	Constitution of Kenya
COP	Conference of the Parties to the UN Framework Convention on Climate Change (UNFCCC)
CTCN	Climate Technology Centre and Network
DANIDA	Danish International Development Agency
EU	European union
GESIP	Green Economy Strategy and Implementation Plan
GHG	Green Houses Gases
GoK	Government of Kenya
HH	Household
INDCs	Intended National Determined Contributions
Ksh	Kenyan Shilling
KNBS	Kenya National Bureau of Statistics
kw	Kilo Watt
kWh	Kilo Watt Hour
LPD	Litres per day
LHD	Litre per household per day
MoENR	Ministry of Environment and Natural resources
MoWI	Ministry of Water and Irrigation
MTP	Medium Term Plan of Vision 2030
MW	Mega Watt
NCCAP	National Climate Change Action Plan
NCCRS	National Climate Change Response Strategy
NEMA	National Environmental Management Authority
NGOs,	Non-Governmental Organization
NWMP	National Water Master Plan
O&M	Operation and Maintenance
PPP	Public Private Partnership



PV	Photovoltaic
RE	Renewable Energy
RETs	Renewable Energy Technologies
SDGs	Sustainable Development Goals
SWTs	Small Wind Turbines
TNA	Technology Need Assessment
UDP	UNEP DTU Partnership
WASH	Water sanitation and Hygiene
WASREB	Water Services Regulatory Board
WEPS	Wind Electric Pumping Systems
WRUAs	Water resource users associations
WSPs	Water services providers
WSTF	Water Services Trust Fund

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### E.1 Background

Since 1974, the government of Kenya has recognised water supplies as critical for poverty reduction and development. Kenya's economic and social development Vision 2030 emphasises the need for adequate and sustainable provision of water supply and sanitation services, with a target to achieve universal access by 2030. However, thus far most water development targets have not been achieved. Improvement has been much slower in rural and low income urban areas, and the current funding level is inadequate to achieve universal access by 2030.

Over the years, official effort have been complemented through non-programmatic community and self-help action, but many projects quickly deteriorate after implementation and are rarely functioning 5 years after implementation. Consequently, water services available for the poor in Kenya are often inadequate, unsafe and unsustainable. Weak attention to planning, standards and operations and maintenance, including source and cost of energy in rural and peri-urban water supplies is a key challenge to functionality and sustainability.

In addition, climate change and variability add to a multitude of immediate and long-term impacts on water resources and on sustainable economic growth. Arid and Semi-Arid areas in the Northern part of Kenya and poor peri-urban areas are particularly vulnerable, characterized by low level of water service provision and acute water scarcity, where water demand considerably surpasses availability. Coincidentally, the areas that are affected by poor water services are the same ones that suffer high rate of unemployment and poverty, low economic output and poor provision of basic services such as sanitation, education and health. All these issues together highlight the need for improved water access in underserved areas and a more sustainable and strategic management of water resources.

The Water Services Trust Fund's (WSTF) mandate is focused on financing investments for underserved rural and low income urban areas. The Water Act of 2016 has transformed WSTF's mandate from just financing water supplies and sanitation to a wider Water Sector Fund role. WSTF through Kenya Industrial Research and Development Institute (KIRDI), the national designated entity (NDE) requested support from the Climate Technology Center Network (CTCN) to "Catalyse low cost technologies for sustainable water service delivery in Northern Kenya". The objective of the technical assistance was to analyse the technical, economic and social potential of three selected green technologies (water pans, solar and wind) for water supply in rural and peri-urban areas.

The present study examines the performance and barriers associated with the technologies and suggest necessary measures to enhance their performance. Assessing the applicability and viability of technologies is critical towards improving water supply especially in the underserved areas. The key findings emanating from this study will inform the water sector in Kenya and especially WSTF on the potential of the selected technologies and their deployment to guarantee sustainability of the water supply.

## **E.2 Water and Climate Risk**

Water scarcity in Kenya has for long been a major issue. The annual per capita freshwater endowment is estimated at 427m<sup>3</sup> in 2016, which means that water is chronically scarce. The current population of 47.3 million people (2016) is roughly distributed according to rainfall endowment, which underscores the importance of reliable water supplies for economic development and livelihoods. Climate change places extra stress on water resources and additional consideration in planning of infrastructure.

Several policies and strategies have been developed with the aim to entrench green growth in sustainable development. The technology need assessment (TNA) for climate change and adaptation in Kenya prioritised agriculture and water sectors, emphasizing that water is an important natural resource critical for sustainable development. The prioritised water sector interventions for water resources include:

- i. Increasing capture and retention of rain water through the construction of water ways, strategic bore holes recharge and other water harvesting methods
- ii. Rehabilitating rivers and dams to improve carrying capacity, storage and water quality
- iii. Developing structures and technologies to ensure availability of water during the dry season

The National Water Master Plan (NWMP) sets out to develop 17,860 small dams and water pans adding an additional 893 Mm<sup>3</sup> water storage by 2030. Kenya's rural electrification rate is about 7% and 50% in urban areas. The government's ambitious plan to increase electrification rates targets to achieve 40% rural electricity access by 2024. This implies that off-grid electricity and small water storage structures will have an important role in medium and long-term water development, especially in rural and low income areas.

## **E.3 Capacity and Prevalence of Technology**

Water pans are found in all parts of the country, with high prevalence in semi-arid to arid areas. Though water-pans were initially intended to addresses livestock water demand, currently they are also used for domestic purposes due to lack of alternative sources and erratic rains. In the humid and semi-humid areas, other types of small storage structures, although not many, are common.

Most water pans were observed to completely dry immediately after the rain, while others had water for 2-3 months after. The high non-functionality rate of water pans is due to poor sizing, siting and site investigation. To maximize the benefits and meet water demand, it is necessary to develop well-designed water pans with a minimum size of 30,000 m<sup>3</sup>. This will entail enhancing skills and information that are needed for planning, design, deployment and management of selected technologies.

At least 347 mechanical wind systems have been deployed for rural water supplies pumping in Kenya since 1980's. However, the uptake has steadily declined with the arrival of solar technology. Most of the mechanical wind installations are no longer functioning and have been replaced by solar systems. Whereas 25 mechanical wind systems have been deployed in the survey counties, only five were

observed during the field study and of those only one was operational. The main cause of failure in mechanical wind pumping is often the deficient basic maintenance. This underlines the need for suitable post-construction support. Small wind electric turbines (SWTs) are rarely used for water supply in Kenya. Information on SWTs and wind data is often inadequate to guide investment decisions. Implementers and suppliers blamed the high cost of the mounting frame for their low acceptability.

Use of modern sources of energy (solar, wind technology, diesel and grid electricity) in water supplies is commonly linked to abstraction of groundwater. Grid electricity was dominant source of abstraction energy in peri-urban areas, and probably for ease of access.

Solar PV was in use across all the ecological zones and predominantly in arid and semi –arid zones, accounting for 80% of the solar installations observed. Mostly, the surveyed solar systems were small-sized (up to 81% had less than 1.5 kW). This limited its application to very small communities, ideally with small head lift requirement. Added to the limited installation skills, varying solar irradiation because of cloudiness and orientation of modules, it contributes to lower power output and intermittent supply in Embu and Baringo. On average 46% of boreholes had a safe yield of 4-6 m<sup>3</sup>/hr or 32-48 m<sup>3</sup>/day. This is sufficient for domestic and livestock demand for roughly up to 104 households. In practice, the size of a community that can be supported by the specific technology setup will depend on the specific water uses and technology attributes.

There were different uses of water with domestic water at 96%, livestock 74 and 28% for small scale irrigation. The mean consumption among the surveyed users was 125 litres per HH per day with an average of 141 and 162 households using one borehole and water pans respectively. Water uses across the ecological zone with small scale irrigation uptake is 74% in Embu, 15.4% in Baringo, 6.7% in Isiolo and 2.9% in Homabay.

There is general view that solar, wind pumping systems and water pans are inferior technologies suited only for smaller applications. There is need to demonstrate that solar, wind systems and water pans are durable and suitable for small and large engineered applications alike.

The following is observed in relation to maintenance and durability of technology deployed for water supplies:

- i. Technology implementers are concentrating on development with minimal or no focus on post-construction follow up. The poor maintenance that results undermines the credibility of the technology and the well-being of served populations.
- ii. The management capacity of community water committees drops dramatically over time as trained people lose interest, lack access to skill upgrading or simply move away. More technologically complex or larger number of users will further increase the management challenges beyond what communities can handle on their own.
- iii. Spare parts, equipment and trained skills for maintenance are difficult to find. Private sector approaches based on “private operator” and ‘pay-per use’ are showing potential for delivering

technology maintenance in poorer and dispersed communities, but the tested cases are too few and too young for inference.

#### **E.4 Preference and Equity**

Community managed water supplies is predominant in rural and peri-urban areas in all the four counties. The majority of users expressed satisfaction with the performance of solar technology, while less contented with the performance of water pan mainly because of the low water quality. User perception of technology effectiveness was mainly influenced more by its capability to guarantee uninterrupted flow of water (reliability) than to supply water of acceptable quality. Few complaints were raised in the humid areas over the limited duration that solar pumping functioned (about 8 hours daily) and low output on cloudy days.

The utilisation of solar energy has enabled the creation of mini-networks that connected water kiosks and individuals around the water source. This demonstrates the potential of solar PV systems to increase convenience and reduce the effort required to collect water.

Selected technologies triggered inclusion, participation and spread of benefits to both men and women. Nonetheless, the youth were disproportionately disadvantaged, as they are rarely involved in the planning and management of water supply systems.

Water investments especially in the rural and peri-urban areas are routinely guided by available finances and resources. This tends to compromise on size and capacity of technology developed. Precondition of 10-30% capital co-contribution by communities further limits the potential of large scale application of selected technologies and subsequently the impact of these investments.

#### **E.5 Capital, Operation and maintenance cost**

Water supply projects in rural and peri-urban areas experienced most serious challenge in operation, maintenance and cost recovery aspect. More than often, the user community collected and managed tariffs but often inadequate for O&M operations.

Capital cost for rural and low-income water supplies technologies are small with 87% of all technologies surveyed costing less than Ksh 10 million, and 53% costing less than Kshs 1 million. The average cost of a borehole surveyed is Ksh 3.45 million, while water pans had an average capacity of 17,800 m<sup>3</sup> and cost Ksh 5.4 million.

Most projects in rural and peri-urban areas are funded by donors and government. Donors and NGOs contributed to capital investment in 48% of the technologies at an average 80.5% of the capital cost. The government on the other hand was involved in financing 46% of these technologies, contributing 76% of

the reported CapEx. Overall, the beneficiary communities contributed on average 19.5% of the total cost but up to 30% in some instances.

Post-construction maintenance (equipment breakdown, lack of spare parts, burst and leakages, siltation, embankment failure, and unreliable source of pumping energy) was considered by managers to represent 53% of the challenges experienced with the technologies' application. The O&M coverage is 52%. Energy cost is significantly high representing up to 50% of the O&M cost and up to 96.5% of the revenue collected. This would leave the water management committees with little or nothing to maintain or expand the water supply system.

## **E.6 Market Risk and PPP Potential**

Inferior quality and substandard products, poor service condition, limited financial capabilities, low demand and local preferences are the main risks contributing to low technological base in rural and peri-urban water supply. These risks constrain the value adding potential linked to the development of low cost green technologies. Inadequate project planning, construction quality control, and poor catchment condition has contributed to neglect of O&M has contributed to lowering the functioning and sustainability of the technologies, and eventually in loss of the entire investment.

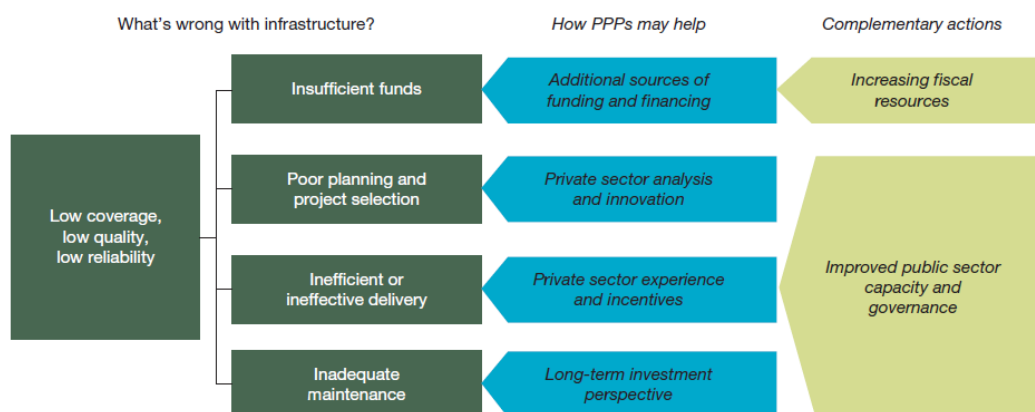
Increase in substandard product and wide variety of technology brand becomes problematic for professional maintenance. Maintenance providers are confronted with high unit costs associated with serving sparse populations in regions with poorly maintained roads. Nonetheless, with technological advancement adequate management and monitoring mechanisms are possible taking advantage of improved mobile telephony and IT backbone.

The high density of unregulated alternative water supply sources often kinked to the grant character of rural and low-income water investments has negatively impact of payment behaviour and contributed to a weak or inexistent financing mechanism. Inadequate revenue owing to insufficient capacity to collect and account for revenue was recurrent in all the four counties. This limits creditors' confidence in the likelihood of water supply business to generate steady future revenue.

Full recovery of capital costs through user fees is rare. Widespread capital investment by private enterprises and entrepreneurs remains unlikely without external subsidies. The few people served by the technology and low water consumption do not create requisite ingredients for generating sufficient revenues. Rural and peri-urban communities lack economic diversity owing to the nature of their livelihoods, which in return limits their capacity for loan re-payment. This challenge may be overcome by clustered management of technology and stimulating activities that simultaneously improve livelihoods and water demand.

Figure E-1 describes how PPPs could assist in addressing the problem of low coverage, low quantity and low reliability in rural and peri-urban water supplies. PPPs can play a greater role in injecting sufficient fund for water development and support in maintenance thus ensuring effective service delivery in these areas.





**Figure E-1: How PPP can help infrastructure delivery (source, Private Sector Provision of WSS in rural areas WSP-World bank, 2016)**

## E.7 Summary and Recommendations

Rural water supply present diverse problems ranging from; low coverage, poor management, neglect in O&M component, lack of technical skills, poor designs and constructions and poor attention to renewal of existing infrastructure. These challenges more than often have resulted to these systems being non-operational and to greater extent dysfunctional. Low cost green technologies if well planned and designed provide innovative solution to these problems and therefore provide an impetus for improved service delivery in rural and peri-urban areas. These green technologies compared to conventional technologies have low recurrent costs and their deployment is therefore likely to free more resources towards maintenance and management, thus guaranteeing their sustainability.

The following recommendations support successful deployment of the selected technologies:

- i. Social groups and long-term sustainability of markets need to be taken into account in design of financial instruments to support storage structures and solar pumping systems.
- ii. Consideration of climate change impacts should be made explicit requirement in planning for rural water supplies.

- iii. Operation and maintenance is central to ensuring technology sustainability. High recognition of this need may entail developing a management model to deploy requisite skills and/or post implementation support units at the county level
- iv. Urgent measures are needed to bring rural water supplies under regulation, and to support viable commercial operations in complement with community roles for water supply management. This may include clustering measures to create water demand
- v. Explicit effort is required to develop capacity and ensure that qualified professionals assume responsibilities for rural and peri-urban water services.
- vi. Continuous monitoring of technology performance to providing lessons and planning baseline.
- vii. Project designs should address the needs of all social groups within the community and especially prioritise opportunities for youth employment.



# 1. Introduction

*This chapter introduces the background for the feasibility study, its key objectives and presents the structure of the report.*

Water supply and sanitation in Kenya are characterized by low levels of access and poor service provision. Despite the technological leaps and enhanced financial investment in the water sector in the last decade, progress towards improved access to water and sanitation services is at a staggering low. It is estimated that 22.2 million or 47%<sup>1</sup> of the Kenyan population still lack access to improved water services, (WSRB, 2016). Water scarcity and climate change exacerbates the difficulty to water access especially in the Arid and Semi-Arid Lands (ASAL) regions in Kenya. These phenomena are expected to have significant effects on water safety and security, altering patterns of availability and distribution, and increasing water contamination.

Furthermore, Kenya sustainable economic growth is threatened by vulnerability to climate change. It is estimated that 42% of the country's GDP and 70% of total employment is derived from natural resource sectors namely: water supply, energy, forestry, agriculture, fishing and tourism. While climate change will lead to adverse impacts across all of these sectors, the water sector stands apart as particularly vulnerable due to its supporting role to the other sectors.

Figure 2 shows the ASALs regions which forms 83% of the country's land surface. These areas together with peri-urban areas are largely characterized by low water service levels. In addition to these areas having low level of water supply, they also have poor provision of structures and limited management skills to support water services<sup>2</sup>. The functionality as well as the sustainability of rural and peri-urban



**Figure 2: Arid and Semi-arid areas in Kenya**

<sup>1</sup> Other sources indicate standard 59% the difference is the criteria for improved water supply

<sup>2</sup> Example, the average access to improved water supplies in five ASAL counties of Garissa, Isiolo, Marsabit, Wajir and Turkana is 37% compared to national average of 59% (Global, Aps, Person, & Callejas, 2015)

water supplies are key challenges because of high cost of operation and maintenance. The cost of energy has a direct implication on the quality and price of water services. Many experts have suggested that technologies such as solar, wind, and small-scale hydropower are not only economically viable sources of energy for water supply but also ideal for supply in disadvantaged areas (Kamp & Vanheule, 2015).

With the foregoing in mind, Water Services Trust Fund (WSTF) requested for technical assistance from the Climate Technology Centre and Network (CTCN) to catalyse low cost green technologies<sup>3</sup> for sustainable water service delivery in Northern Kenya and peri-urban areas. UNEP-DTU Partnership (UDP) was contracted by CTCN for technical assistance to:

- (a) analyse the feasibility and sustainability of the deployment of three low-cost green technologies for improving water services for household consumption, irrigation, in underserved ASALs in Northern Kenya and in peri-urban areas;
- (b) Analyse private sector engagement potential in their deployment.

Hence, the specific objectives of the technical assistance are to:

- i. Determine the technical, economic and social feasibility of three water technologies for the targeted areas, through a feasibility study entailing in-depth primary and secondary data collection and analysis.
- ii. Identify potential private sector actors and Public Private Partnerships (PPP) within the water sector for the deployment of green water technologies.
- iii. Develop a PPP business model in collaboration with relevant stakeholders and build their capacity to engage in PPP.
- iv. Develop a concept note to trigger future funding i.e. to enable piloting of technologies, supporting implementation of PPP.

### **1.1. Study Objectives**

The present feasibility study identifies the contextual features that allow use or limit the viability of selected technologies in areas (counties) with less developed infrastructure, in the wider view of sustainable water supply. The objective of the feasibility study is thus to assess the technical, economic and social feasibility of three water technologies for the targeted areas, through in-depth primary and secondary data collection and analysis.

Specifically, the feasibility includes an analysis of the:

- i. Technical feasibility (types of technologies, durability, viability and materials required, skills and knowledge, potential providers).
- ii. Economic Feasibility (cost effectiveness, price of materials, operation and maintenance costs, current demand and supply, cost recovery, financing)
- iii. Social feasibility of the chosen technologies (potential to create employment, social acceptability, awareness attitude and perception of the technology, land use patterns, gender and governance issues)
- iv. Risks, sustainability and reliability potential of these green technologies.

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<sup>3</sup> Green technology encompasses a continuously evolving group of methods, materials and systems for generating services while conserving the natural environment and resources and/or mitigate or reverses the effects of human activity on the environment:

The feasibility study and subsequent implementation of the CTCN technical assistance contributes to WSTF's strategic objective of "financing sustainable water and sanitation services in underserved rural and urban areas" (WSTF, 2014) and contributes to national priorities and planned development programs in the water and environment sectors in Kenya.

The feasibility report will follow the following structure;

## **PART I**

**Chapter 1: Introduction;** this chapter introduces the water supply situation in Kenya with main focus on the rural and peri-urban setup. The study background and objectives are outlined in this chapter.

**Chapter 2: Conceptual Framework;** the chapter outlines the study framework which includes; description of sampling, data collection and assessment methods adopted for this study. The chapter outlines a brief exploratory description of Field Data.

**Chapter 3: Study Areas;** this chapter explains the choice of study areas as a representative of different agro-climatic zones in Kenya.

**Chapter 4: Water and Green Growth;** this chapter outlines water challenges in Kenya in the wake of climate change. It delineates the historical behaviour of the selected technologies

**Chapter 5: Overview of the selected Green Low Cost Technologies;** this chapter describes the application of the selected green technologies in Kenya.

## **PART II**

**Chapter 6: Capacity, Prevalence and Functioning of Technologies;** this chapter describes the technical analysis based on technology reliability, capacity and durability.

**Chapter 7: Effectiveness and sustainability of low cost Green Water Technologies;** this chapter describe the economic analysis using the cost benefit analysis of the selected green technologies. This analysis is based on the capital, operation and maintenance cost of the different technologies. It provides a comparative analysis on the cost of different technologies observed.

**Chapter 8: Analysing Technology Preference and Access;** this chapter describe the social analysis of the selected technologies. The analysis here is based on the level of technology acceptance and its ability to promote transformation and inclusiveness across all social groups.

**Chapter 9: Technology risks and sustainability Analysis;** this chapter describes the possible technology risks that may impact on the deployment of the selected technologies.

**Chapter 10: Developing Green solutions for water supply;** the chapter highlights various mechanisms that will promote the scaling up of green technology for sustainable water supply.

**Chapter 11: Key Messages/recommendations;** this chapter filters key lessons through the field study lens and provides a framework for improving quality and coverage of water supply.



## 2. Conceptual Framework and Methodology

*This chapter presents the stepwise process followed in selecting the target low cost green technologies. It introduces the main research questions, the conceptual framework and methodology applied in the feasibility study.*

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The feasibility study is based on the hypothesis that low cost green technologies have the potential to sustainably improve access to safe drinking water and sanitation services in Kenya. The study followed a stepwise process assessing the applicability, scalability and sustainability of each selected technology in order to provide lasting services in a specific context. The analysis also addressed the readiness for its introduction. The process entailed the application of quantitative and qualitative methods elaborated in section 2.3 to assess:

- the technical feasibility (types of technologies and materials required, skills and knowledge required and potential technology providers),
- the economic feasibility (cost effectiveness, price of materials, operation and maintenance costs, current demand and supply) and
- the social feasibility (potential to create employment, attitude and perception, land use patterns, gender and governance issues) of the selected low cost technologies.

### 2.1. Selection of technologies – Technical, social, economic and environmental parameters

The green water technologies were selected from a list of five (5) technologies identified by WSTF when submitting request for assistance.

- a) Solar water pumping system
- b) Wind powered pumping systems,
- c) Sand dams (sub surface rainwater water storage technology),
- d) Djabias (Semi-underground tanks with water catchment systems),
- e) Water pans (small surface rainwater storage)

The technologies are all low-cost simple technologies involving either renewable energy or enhancing water storage and are appropriate for underserved communities. The five technologies were evaluated and prioritised through a multi-criteria analysis using a combination of weighted criteria based on the following criteria and which will be subject to an in-depth analysis:

- i. Priority areas for available funding
- ii. Cost of technology (initial investment, operations and maintenance)
- iii. Potential to improve livelihood and grow local economy
- iv. Availability of requisite skills for installation, operations and maintenance
- v. Capacity to enhance water quality and quantity
- vi. PPP potential for the selected technologies
- vii. Potential deployment across the country, and
- viii. Potential to reduce emission and increased resilience to climate change and variability

Table 1 and Table 2 indicate the relative technology score for the identified ranking factor and the Weighted Score and Prioritised Technology respectively.

**Table 1: Relative technology score for the identified ranking factors**

	Costs		Benefits							
	O&M costs	Capital costs	PPP Potential	Livelihood improvement, employment and economic empowerment	Availability skills to supply installation, running and maintenance	Potential deployment across country	Capacity to enhance water quality	Capacity to enhance water quantity	Potential to reduce GHG emissions	Potential to increase resilience to climate change
<i>Technology 1: Solar water pumping system</i>	8	6	9	9	4	8.5	8	9	10	7
<i>Technology 2: Wind powered pumping systems or wind mill</i>	8	5	8	8.5	2	8	8	9	10	7
<i>Technology 3: Sand dams (run off water harvesting technology)</i>	9.5	8	4	7	8	5	8	5	5	8.5
<i>Technology 4: Djabias (Semi-underground tanks with water catchment systems)</i>	8.5	8	2	4.5	8	9	3	3	5	6
<i>Technology 5: Water pans (run off water harvesting technology)</i>	6	4	6	8	7	7	2	5	5	7

**Table 2: Weighted Score and Prioritised Technology**

	Costs		Benefits								Total Score
	O& M costs	Capital costs	PPP Potential	Livelihood improvement, employment, economic empowerment	Availability skills to supply installation, running and maintenance	Potential deployment across country	Capacity to enhance water quality	Capacity to enhance water quantity	Potential to reduce GHG emissions	Potential to increase resilience to climate change	
<i>Technology 1: Solar water pumping system</i>	64	48	72	117	52	34	32	117	130	91	602
<i>Technology 2: Wind powered pumping systems or wind mill</i>	64	40	64	110.5	26	32	32	117	130	91	551.5
<i>Technology 3: Sand dams (run off water harvesting technology)</i>	76	64	32	91	104	20	32	65	65	110.5	473
<i>Technology 4: Djabias (Semi-underground tanks with water catchment systems)</i>	68	64	16	58.5	104	36	12	39	65	78	394.5
<i>Technology 5: Water pans (run off water harvesting technology)</i>	48	32	48	104	91	28	8	65	65	91	441
<b>Criterion weight</b>	<b>13</b>	<b>8</b>	<b>8</b>	<b>13</b>	<b>13</b>	<b>4</b>	<b>4</b>	<b>13</b>	<b>13</b>	<b>13</b>	

## 2.2. Research Questions

For a clear understanding of the feasibility study and its objectives, three main research questions were developed in line with the key areas of analysis (technical, economic and social feasibility):

- Do the identified green technologies provide a functional mechanism for climate proofed water supply?
- Do the identified green technologies provide good value and continuous benefits?
- What are the community attitudes and perceptions towards the three technologies for water supply?

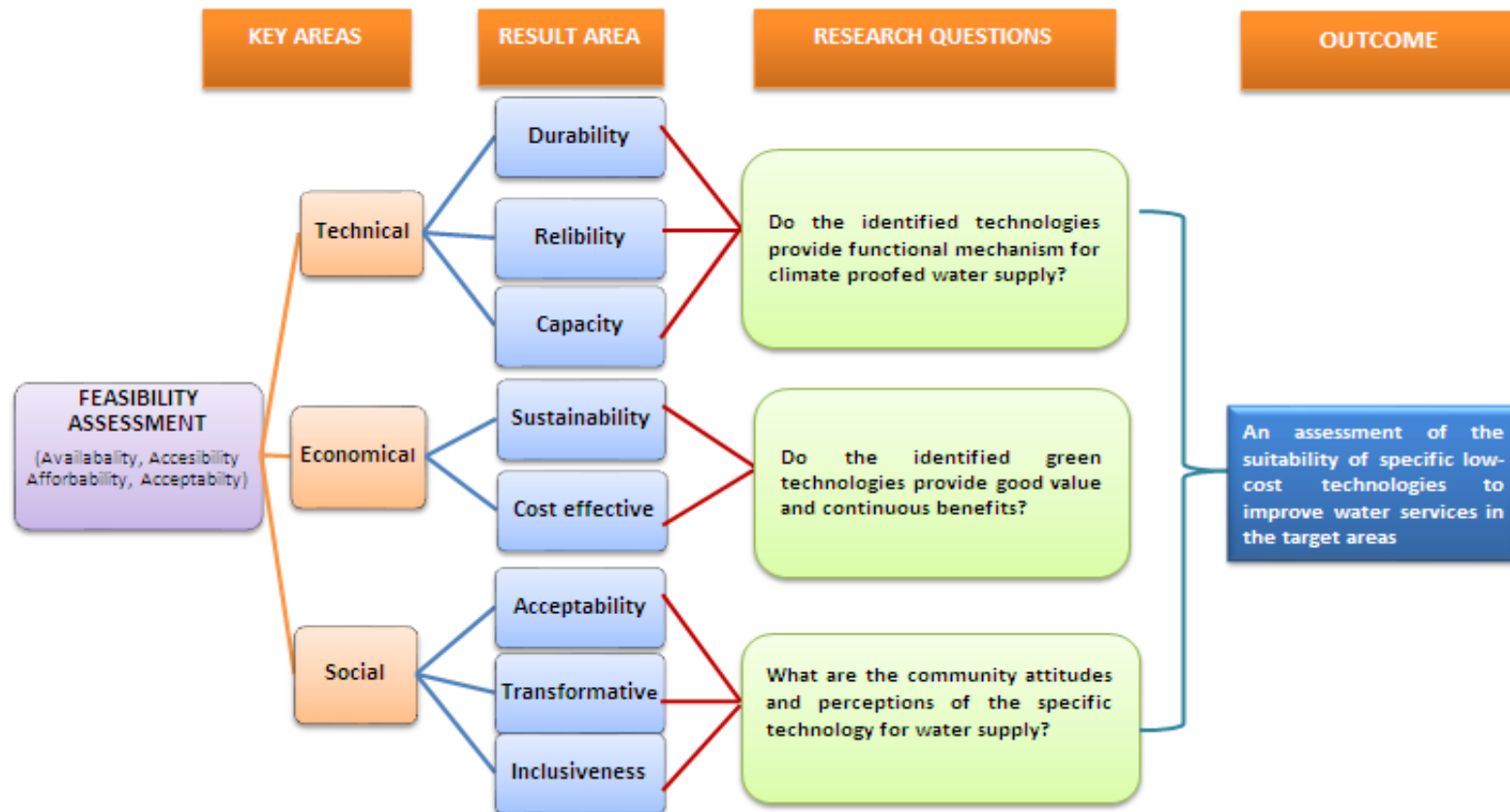


Figure 3: Key result areas and research questions

Based on the research questions outlined above sustainability indicators were identified in order to provide a basis for the in-depth analysis. These indicators focus on the functional conditions of the selected technologies which include financial, social, institutional, legal, environmental, technical, and capacity-related aspects, from the perspectives of three key actor groups: (i) users/buyers, (ii) producers/providers, and (iii) regulators/investors/facilitators. For each match of dimension and perspective an indicator was selected and questions developed. Table 3 provides a summary of the sustainability dimensions which are relevant from the perspective of different key actors.

**Table 3: Technology adaptation indicators from the perspectives of different actors (adapted from Hostettler & Hazboun 2015)**

		Perspectives of Key Actors		
		User/buyer	Producer/Provider	Regulator investor facilitator
Sustainability Dimensions	Social	1) Demand and preference of the technology	2) Technology uptake	3) social marketing and equitability
	Economics	4) Affordability / Price	5) Cost recovery/ Profitability	6) Public Benefit (priorities)
	Environmental	7) Water quality	8) Resilience of water supply	9) Reduce vulnerability, impact on health
	Legal and Institutions	10) Responsive to needs and users friendly	11) Model of delivery, access level	12) Alignment laws/policy/strategies
	Skill and Knowledge	13) Ease to use and manage	14) Skills for operation and maintenance	15) Capacity for monitoring, evaluation and technology validation
	Technological	16) Capacity, reliability to meet demand	17) durability , serviceability	18) Deployment/ up-scaling technology

### 2.3. Description of sampling, data collection and assessment Methods

In designing this study, the four selected counties were drawn upon the nationally representative sample within the seven ecological zones in Kenya ranging from humid to very arid shown in Table 4. Additionally, the study entailed understanding the water supply systems in peri-urban setting in the selected counties.

The seven agro-climatic zones in Table 4 are categorised using a moisture index (Sombroek, Braun, & van der Pouw, 1982) based on annual rainfall, which is expressed as a percentage of the potential evaporation. Areas that are categorized as zones I, II and III have an index greater than 50% and are considered zones good for cropping; they account for 12% of the country land. Zones V, VI and VII are considered to be ASALs regions which have an average rainfall of < 900 mm, accounting for 83% of the land.

**Table 4: Classification of Agro-climatic zones, (Country Pasture/Forage Resource Profiles (Kenya) n.d.)**

Agro - Climatic Zone	Classification	Moisture Index (%)	Annual Rainfall (mm)	Land Area (%)
I	Humid	>80	1100-2700	12
II	Sub-humid	65 - 80	1000-1600	
III	Semi-humid	50 - 65	800-1400	
IV	Semi-humid to semi-arid	40 - 50	600-1100	5
V	Semi-arid	25 - 40	450-900	15
VI	Arid	15 - 25	300-550	22
VII	Very arid	<15	150-350	46

Further, study areas within these counties were identified through cluster sampling through the use of administrative and electoral boundaries. The electoral wards within each county were listed and used as the basic clusters. The study clusters were then randomly selected from the list of electoral wards. Once the study clusters were identified snowball sampling technique was used to identify particular technologies. Technology operators in the identified points responded to the water manager survey questionnaire whereas randomly selected users at the water point responded to the water user survey questionnaire.

The data and information needed was collected through secondary data collection (e.g. extensive desk studies including scientific articles, reports etc.) and primary data collection through structured and semi-structured interviews, key informants interviews and focus group discussions (*see. Annex 5*). The use of mobile application in the collection of data ensured few data error as well as reducing time lag between data collection and data entry. Use of varied survey tools (Water Managers survey questionnaire, Water user survey questionnaire, Key informant interviews and focus group discussions) allowed for triangulation of data enhancing the quality of data collected.

### **Summary of the research design**

The Table 5 summarises the study research design. It highlights various sources of data, data collection and analysis method



Table 5: Summary of study design

Research question	Specific Result Area	Source of Data	Data collection techniques/tools	Data Analysis	Interviewees
Do the identified technologies provide functional mechanism for climate proofed water supply?	Assessing Technology Durability	<ul style="list-style-type: none"> <li>- Water sector stakeholders (MoWI, county Governments, WSPs)/partners(NGOs, CBOs, donors)/ beneficiaries</li> <li>- WSTF and other Water sector institutions</li> <li>- Documents</li> </ul>	Literature review, Survey questionnaire, Key Informant Interviews (KIIs), SSI, Focus Group Discussions (FGDs), observation	- Frequencies for quantitative data	Selected stakeholders (County Government, WSPs, MoWI, MENR, NGOS, CBOs, WRMA, WASREB, WRUAs)
	Assessing Technology reliability	<ul style="list-style-type: none"> <li>- Water sector stakeholders/partners/ beneficiaries</li> <li>- WSTF and other Water sector institutions country programs document</li> </ul>		- thematically for qualitative data	
	Assessing Technology capacity	<ul style="list-style-type: none"> <li>- Water sector stakeholders/partners/ beneficiaries</li> <li>- WSTF and other Water sector institutions country programs document</li> </ul>		- graphical and contingency table for Categorical, ordinal and interval data	
Do the identified green technologies provide good value and continuous benefits?	Assessing Technology cost effectiveness	<ul style="list-style-type: none"> <li>- Water sector stakeholders (technology supplies for water pans, wind and solar pumps/partners/ beneficiaries</li> <li>- Capital cost O&amp;M plans (if available) services</li> </ul>	Literature review, survey questionnaire, KIIs, SSI, FGDs	<ul style="list-style-type: none"> <li>- SPSS for quantitative data</li> <li>- graphical and contingency table for Categorical, ordinal and interval data</li> </ul>	Water Committee and technology caretakers, technology suppliers, technology financiers
	Assessing Technology sustainability	<ul style="list-style-type: none"> <li>- Water sector stakeholders/partners/ beneficiaries</li> </ul>	Literature review, survey questionnaire, KIIs, SSI, FGDs	- graphical and contingency table for Categorical, ordinal and interval data	
What are the community attitudes and perceptions of specific technology for water supply?	Assessing Technology acceptability	<ul style="list-style-type: none"> <li>- Community water committees, beneficiary community</li> </ul>	User survey questionnaire, KIIs, FGDs, observation, KIIs, FGDs, observation	<ul style="list-style-type: none"> <li>- Graphical and contingency table for Categorical, ordinal and interval data</li> <li>- thematically for qualitative data</li> </ul>	Technology beneficiaries, technology user
	Assessing Technology outcomes and emerging impact (transformative)	<ul style="list-style-type: none"> <li>- Community water committees, beneficiary community</li> </ul>		- graphical and contingency table for Categorical, ordinal and interval data	
	Assessing the technology ability to influence community inclusiveness	<ul style="list-style-type: none"> <li>- Community water committees, beneficiary community</li> </ul>		- thematically for qualitative data	

## 2.4. Exploratory Description of Field Data

Field data was collected from the four selected counties to represent different ecological zones in Kenya. In total, 87 technological points were part of the survey using the Water manager tool and an additional 27 points were collected from the case study tool<sup>4</sup>, totalling 105 technology points. Interviews were conducted with 87 technology managers, 133 users and 20 key informant interviews and focus group discussions were conducted in the field. Table 6 shows the distribution of respondents across the study areas. The users were selected randomly from people found at the technology points and of the 133 interviewed, 51% of the users were male and 49 % were female.

**Table 6: Distribution of Survey respondents per county**

County	Technology points	Water Managers	Users	KII	Cases studies	No. of surveyed Wards	Human Population(2009 census)	
							County Total	Population Density
Embu	30	27	42	4	5	3	538,355	183.2
Baringo	24	20	26	7	3	4	555,561	50.4
Isiolo	27	21	30	5	8	3	143,294	5.7
Homabay	24	19	35	4	11	4	1,038,858	302.8
<b>Total</b>	<b>105</b>	<b>87</b>	<b>133</b>	<b>20</b>	<b>27</b>	<b>14</b>	<b>2,276,068</b>	

48% of the technology points visited were located in semi-humid to semi-arid areas, while 29% were located in arid areas. 82% of the technologies surveyed were installed after the year 2000. The most prevalent water source from the visited technology points was boreholes.

Table 7 shows the distribution of survey point by ecological zones in each county.

**Table 7: Distribution of technology survey point by ecological zones per county**

	County				Total	%
	Embu	Baringo	Isiolo	Homabay		
Humid	3				<b>3</b>	3.5%
Sub humid	1	2			<b>3</b>	3.5%
Semi Humid	2	1		5	<b>8</b>	9.2%
Semi Humid to Semi-Arid	21	1	6	14	<b>42</b>	48.2%
Arid		16	15		<b>31</b>	35.6%
<b>Total</b>	<b>27</b>	<b>20</b>	<b>21</b>	<b>19</b>	<b>87</b>	<b>100%</b>
	<b>31%</b>	<b>23%</b>	<b>24%</b>	<b>22%</b>		

<sup>4</sup> Case study tool was a template developed to capture any intriguing features of water supply system in the study areas during the data collection process. The tool assists in systematic capture of information which cannot be fully answered by the questionnaires

### 3. Study Areas

*This chapter explains the rationale behind the choice of the counties of Baringo, Isiolo, Embu and Homabay - representing different agro-climatic zones in Kenya - and provides a brief introduction to all four counties.*

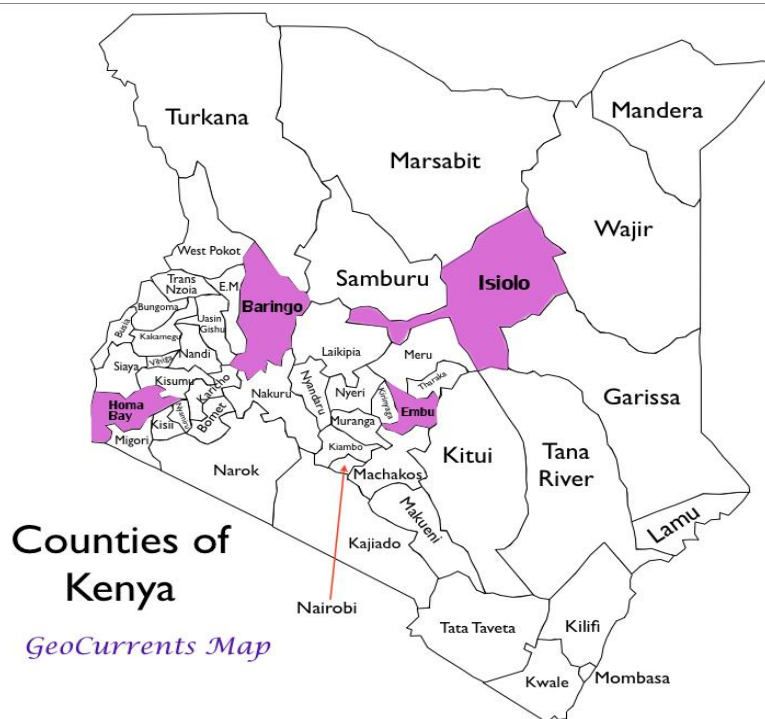
Kenya has climatic and ecological extremes with altitude varying from sea level to over 5000 m in the highlands. The mean annual rainfall ranges from < 250 mm in semi-arid and arid areas to > 2000 mm in high potential areas. Agriculture is the most important economic activity in Kenya and represents more than 26% of gross domestic product, with 75% of the country's population depending on agriculture for food and income generation. Approximately 1/3 of the country's land area is agriculturally productive which includes the lake, coastal and highland regions. The other 2/3 of the land area is semi-arid to arid which are largely characterized by low, unreliable and poorly distributed rainfall. The ASALs areas are normally used for livestock production with livestock production contributing to 26% of Kenya's agricultural production<sup>5</sup>.

Four counties were selected to represent the different agro-ecological zones in Kenya, with priority given to counties identified for WSTF investment programmes funded by the EU and Danida, as these are likely to benefit directly from the results of this study. Table 8 below represents the target counties based on the various ecological zones, the technologies available and WSTF interventions.

**Table 8: Selected Counties for the field Survey**

Select County	Zones covered				Available technologies	WSTF Interventions
	Humid	Semi-humid	Semi - Arid	Arid		
Baringo					3 Technologies (Solar, Wind& Water pans)	European Union
Isiolo					3 Technologies (Solar, Wind& Water pans)	Green growth
Embu					3 Technologies (Solar, Wind& Water pans)	Peri urban experience
Homabay					2 Technologies( Water pans & Solar)	Peri urban & PPP experience

<sup>5</sup> <http://www.fao.org/ag/AGP/AGPC/doc/Counprof/Kenya.htm>



**Figure 4: Study Areas**

### **Baringo County**

Baringo County covers an area of 11,015 km<sup>2</sup> with a population of 555,561 as per the 2009 census. The climate in the county varies from humid in the highland areas to arid in the lowlands. 24% of Baringo county residents use improved water sources but of these 6% are within the services of licenced areas of utilities (Water Services Regulatory Board (WSRB), 2016) . Most of the land is under community trust holding. 30% of the land has been demarcated and ownership deeds issued. Climate change is generally characterised by increased warming and recurrent droughts. Extreme effects of climate continue to impact on the county's ability to provide sustainable water supply to its urban and rural populations.

### **Embu County**

Embu County covers an area of 2,818 Km<sup>2</sup> with a population of 516,212, according to the 2009 population census. Embu County depicts the typical agro-ecological profile of the windward side of Mt. Kenya of cold and wet to hot and dry lower zones in the Tana River Basin. The average rainfall in the upper areas is 2000 mm and 600 mm in the lower areas. The county plays a major role in the national energy sectors as it hosts the seven-folk project that contributes 45% of the country's electricity. 68% of Embu County residents use improved sources of water although 84% of the county population are within services areas of licenced water utilities (Water Services Regulatory Board (WSRB), 2016). 59.6% of land parcels in the county have title deeds. It's generally perceived that the county has experienced its share of climate change through increased drought periods, erratic weather patterns and increased temperature, especially on the lower areas of the county.

### **Homabay County**

Homabay County covers 3,183 km<sup>2</sup> with a population of 963,794 persons according to the 2009 population census. The county is divided into two ecological zones namely the upper and lower midland with an equatorial type of climate. The county average annual rainfall ranges from 700 to 800 mm. 28%

of residents use improved sources of water, with the rest relying on unimproved sources. The population within service areas of utilities is at 14% (Water Services Regulatory Board (WSRB), 2016). 48% of the land owners in Homabay have been issued with title deeds. Climate change in Homabay County is generally characterised by declined stock of fish, drying up of water sources and erratic rainfalls. Further, environmental degradation across the county has resulted in loss of productivity of land affecting crop production, income levels and food insecurity within the county.

### **Isiolo County**

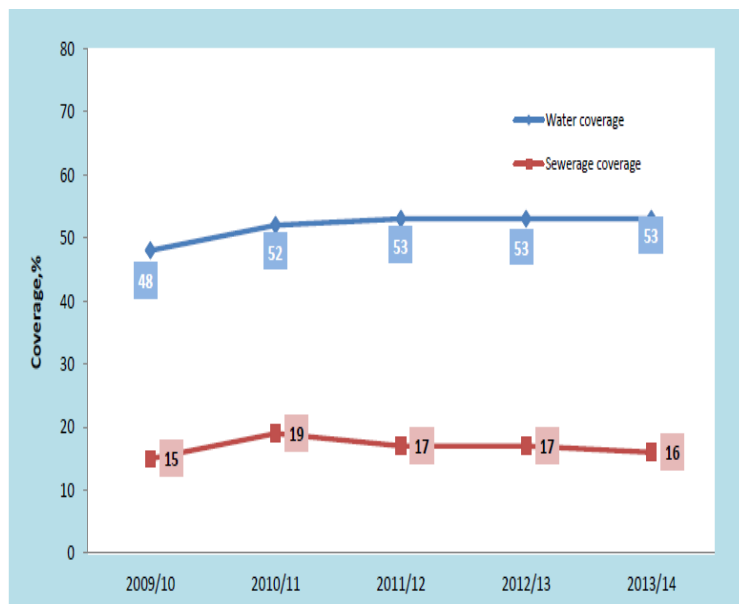
Isiolo County has an area of 25,700 Km<sup>2</sup> with a population 143, 294 according to the 2009 census. There are three main ecological zones in the county: semi-arid, arid and the very arid. The semiarid zone maksh 5% of the county and is characterised by an annual rainfall of between 400 – 650 mm. The arid zone is 30% of the county area with an annual rainfall of 300 to 350 mm. The very arid zone covers the largest county area (65%) and is characterised by annual rainfall of 150 to 250 mm, hot and dry weather and barren soils throughout the year. 59% of residents have access to improved sources of water of these 21% are within the service areas of registered utilities (Water Services Regulatory Board (WSRB), 2016). Isiolo is one of the counties considered to be most vulnerable to climate change in Kenya. Some of the vulnerabilities resulting from climate change are unpredictable rainfalls, floods, droughts, loss of forest and wetland ecosystems and scarcity of potable water.

## 4. Water and Green Growth

*This chapter presents the key challenges related to water resources management in Kenya and introduces the climate risks affecting the water sector, as well as the historical, policy and legal context relevant for this sector*

### 4.1. Situational and historical context

Water scarcity is a serious issue in Kenya influenced by political dynamics, natural availability of water, population and poor governance. In addition there is insufficient capacity, neglect of the water resource base and lack of accountability. Water scarcity is further exacerbated by the profound impacts of climate change on water resources threatening water access, availability and quality. Figure 5 shows that water service coverage has generally remained very low (53% in 2015), (Water Services Regulatory Board (WSRB), 2016), especially in rural areas and peri-urban areas (49%) (WASREB, 2014).



The First National Water Master Plan in 1974 stimulated development of many schemes under the provincial (regional) water and sanitation programmes with the goal of “Water for all by 2000”. The official effort was complemented by non-programmatic community and self-help action<sup>6</sup> championed soon after independence to deliver social services in education, water supply and health. Water services coverage grew rapidly mostly in what was considered as high potential areas<sup>7</sup>, in the central and eastern highland, rift valley and the Lake Victoria basin. By 1998, over 1800 water supply systems under the management of various providers were reported, in addition to privately run sources supplying to the public schemes (MWI, 2015). However, the system turned out to have several weaknesses, particularly with regards to

**Figure 5: Trend in Water and Sewerage coverage, (Water Services Regulatory Board (WSRB), 2016)**

<sup>6</sup> An estimated 2500 water, health and education facilities were developed in the first two decades of the independence, which accounted for approximately 30 % of the rural development investment. Though harambee was a popular tactic to hasten the rural development after independence, many of the harambee projects were expected to be taken over by the government after completion, and sustainable plans for operation and maintenance were not made. Besides Harambee projects were gradually inclined to political patronage and means of gaining influence. Moreover and owing to the unstructured nature of the harambee investment, weak control and lack of accountability made them vulnerable for corruption and mismanagement.

<sup>7</sup> High and medium potential areas in Kenya refer to region with a combination of moderate temperatures, rainfall between 1200 and 2000 mm per annum and productive soils. Generally, these areas correspond to agro-ecological zones I, II and III. They are considered as best suited for intensive agriculture and livestock husbandry, hence the notion of high potential.

sustainability. In most cases, projects quickly deteriorated after the handover to the communities. In some regions the actual number of people with access to water services decreased (Danida, 2010). Coupled with the rapidly growing population, the number of people without water services remained high.

The first attempt to address this challenge in the 4<sup>th</sup> Development Plan (1979-83) diversified roles and responsibilities to beneficiaries, introduced cost sharing in public services, privatized some government functions and removed government subsidies in addition to financial cuts from social programmes. The “District Focus for Rural Development”, promulgated in 1983, decentralised the planning and administration to lower levels of government and in 1986, water service provision was decentralised to local authorities and communities. The after period witnessed very low levels of investment and efficiency in water management. The local authority and community that managed water supplies suffered from neglect of operation, inadequate revenue collection, corruption, over extension of water supply systems and lack of renewal construction. This situation led to an almost total collapse of monitoring systems. The 1992 delineation study on the Water sector in Kenya (Water and Sanitation Program-Africa, 2007) concluded that the government was unable to operate water supplies efficiently and to maintain adequate service level due to financial constraints.

In 1999, Kenya embarked on a radical water sector reform aimed at improving the state of water services and water resource management. Distinct water sector institutions were created separating the water resources management and water services roles on the one hand, and policy, regulatory and implementing roles on the other. The Water Services Trust Fund was established with the aim to finance and operationalize a system that enhances attention to pro-poor water services.

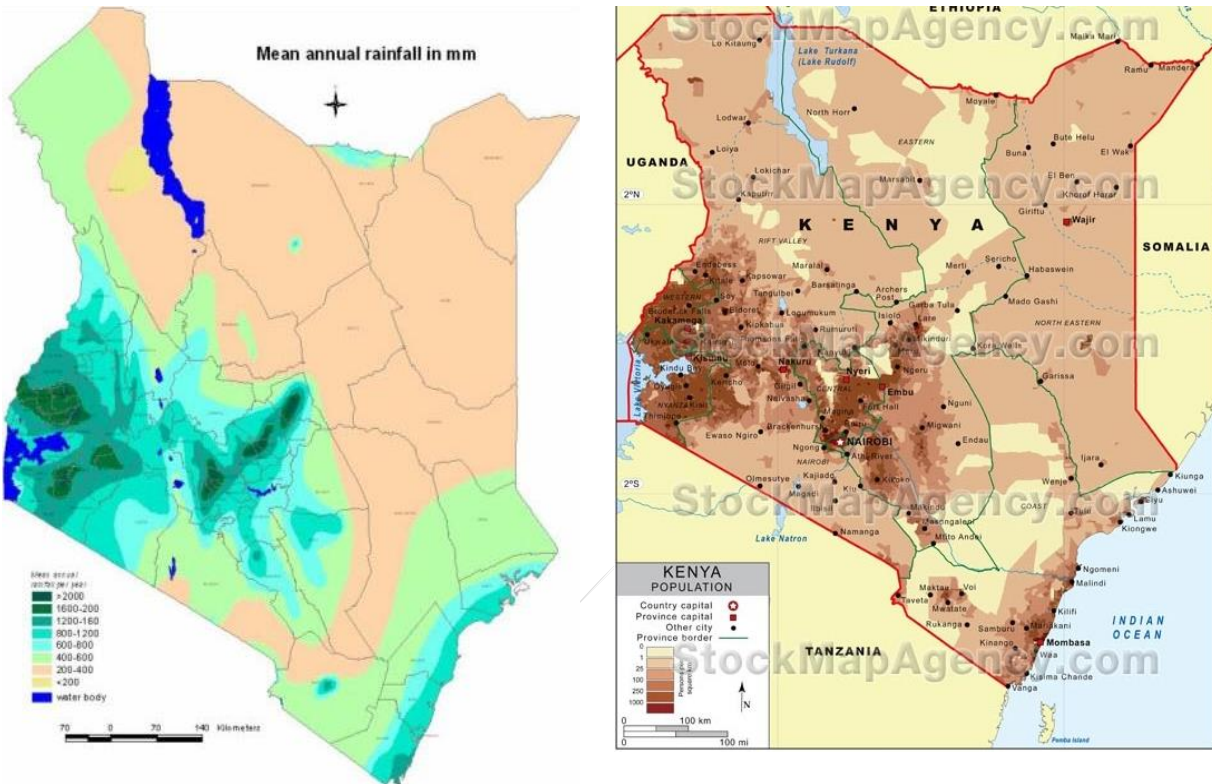
With the implementation of the water reforms, a positive trend has been noted in the critical service provision factors, namely financial investments, improved performance by water utilities and the orientation towards demand. This also included a marked orientation towards the underserved and low income areas. However, by the time the water sector reforms started water development had been broken up into numerous programmes and segments including rural, minor urban water supplies, livestock water supplies, national and community irrigation schemes, self-help supplies. With so many actors involved in the provision of water, there has been great need to coordinate activities by the various players for integrated water development.

Today, the main challenge is to provide water services to more 22 million underserved communities mostly living in rural and densely populated low-income urban areas. With an urbanization rate of 4.28 %, there is an influx of nearly half a million people in towns every year (Water Services Regulatory Board (WSRB), 2016).

Water coverage illustrated in Figure 5 has remained stagnant in the face of pressure exerted by growing population, implying the need for more investment. The state of water coverage implies the target of 80% coverage by 2015 set by the National Water Services Strategy (NWSS) was not reached. On average 14,000 new connections were developed annually in the last 4 years compared to 200,000 connection yearly that are required to achieve the 2030 water supply targets. The latter is fifteen-fold over the present achievement, (Water Services Regulatory Board (WSRB), 2016).

## 4.2. Water and Climate Risk

Kenya is a generally water scarce country with about 83% of the country being arid and semi-arid. The average annual rainfall in Kenya is 630 mm with a wide variation from less than 200 mm in Northern Kenya to over 2000 mm in the central highlands and Lake Victoria region. Kenya's population in 2016, extrapolated from the 2009 census is estimated to be 47.3 million people in 2016, roughly distributed according to rainfall endowment. This reality underscores the importance of reliable of water supplies for economic development and livelihoods.



**Figure 6: Mean Annual Rainfall Vs population density in Kenya**

It is estimated that 42% of Kenya's GDP and 70% of overall employment is derived from natural resource related sectors including agriculture, energy, mining, water supply, forestry and tourism, (GESIP, 2015). While climate change will lead to adverse impacts across all of these sectors, the water sector stands apart as particularly vulnerable due to its supporting role to the other sectors. These include flooding, drought, drying up of rivers, poor water quality in surface and groundwater systems, precipitation and water vapour pattern distortions. These effects when compounded together have devastating impacts on ecosystems and communities, ranging from economic and social impacts to health and food insecurity, all of which threaten the continued existence of many regions in Kenya.



Water supplies in Kenya are hugely dependent on the five water towers of Kenya<sup>8</sup>. Extreme climate change events in combination with population growth and environmental degradation are already changing the water cycle that in turn affects water availability and runoff, and may thus affect the recharge of rivers across Kenya. Kenya's renewable water resources are estimated at 20.2 km<sup>3</sup> per year which correspond to 647 m<sup>3</sup> per capita<sup>9</sup> in 2000, which is considered very low and likely to decrease with climate change. Access to water is most difficult in arid and semiarid regions of Kenya where livelihoods are derived from livestock keeping. Any reductions in surface run-off are likely to impact negatively on pastoral livelihoods through the drying of water sources. On the other hand, rural-urban migration, mostly to peri-urban areas, has accelerated pressure on water resources. An increased incidence of droughts under climate change is likely to increase rural-urban migration and confound urban vulnerability. It is estimated that 32.3% of Kenyans were living in urban centres in 2015, which is projected to increase to up to 50% by 2025 (Kenya National Bureau of Statistics (KNBS), 2012).

Kenya's National Climate Change Response Strategy highlights that observed temperature trends between 1960 and 2006 indicate warming over land in all locations except for the coastal zone. The minimum temperature has risen by 0.7 – 2.0 ° C and the maximum by 0.2 – 1.3 ° C. (Government of Kenya, 2013; Trócaire, 2014). Observational evidence shows that the frequency of dry years is increasing while rainfall has declined significantly since the mid-1960 (Table 9). In addition drought cycles have become shorter, reducing over the years, from every 5-7 years to every 2-3 years.

<b>Table 9: Droughts in Kenya since 1960's, (Masih, Maskey, Mussá, &amp; Trambauer, 2014)</b>	
<b>Year</b>	<b>Number of people affected</b>
1965	16000
1971	20000
1979-80	40000
1983-84	200000
1991-92	1.5m
1995-96	1.4m
1999-2000	2.23m
2003-04	2.23m
2006	2.97
2009	3.79m
2011	3.75m
2014-16	1.6m

<sup>8</sup> Kenya main water towers - the Aberdare Mountains, Mau forest complex, Mount Kenya, Mount Elgon, and the Cherangani Hills are high-elevation forests that are the source for most of the water. Though they cover less than 2% of the country surface area, they are vital national assets in terms of climate regulation, water storage, recharge of ground water, river flow regulation flood mitigation, reduced sediment flow to water bodies and carbon sequestration. The 5 water towers are significant to Kenya's key economic sectors including tourism, energy, agriculture and water supply to rural and urban.

<sup>9</sup> Per capita water endowment is the average annual renewable freshwater availability. Kenya's per capita of 647 m<sup>3</sup> which is frequently cited in several documents refers to year 2000 estimates based in a population of 31,065,820. The estimated population at the end of 2016 was 47,251,449 which translate to 427 m<sup>3</sup> per capita. The term water scarce and chronic scarcity are used when annual renewable freshwater availability fall below 1000 m<sup>3</sup> and 500 m<sup>3</sup> per capita

Climate change and variability is affecting Kenya like many other countries, through disrupting national economies and livelihoods. Table 9 further shows the increasing burden of drought hazard in Kenya. Sustainable development goal 13 calls on countries to “take urgent action to combat climate change and its impacts”. Attaining this goal requires adoption of affordable, scalable solutions that will enhance resilience of their economies. The pace of change is accelerating therefore providing an opportunity to embrace a low-carbon economy, and implement a range of measures that will reduce emissions and increase adaptation efforts.

#### **4.3. Policy, Legal and institutional structure**

The Government of Kenya has responded to various national and international climate challenges through the enactment of various policy, legislation and strategies to address them and meet international obligations. Kenya has completed its National Climate Change Response Strategy (NCCRS) and National Climate Change Action Plan (NCCAP). There is on-going effort to embed climate change to governance in different sectors dealing with management of climate sensitive natural resources.

##### **4.3.1. Constitution of Kenya**

Chapter 11 of the Constitution of Kenya (CoK) 2010 provides for a devolved system of governance aimed at promoting a democratic and accountable exercise of power, the equitable sharing of resources and responsive and effective delivery of services, while empowering citizen’s participation through the process. The system created a two-tier level of government leading to creation of 47 counties led by elected county governments. Each level has its own set of functions which though distinct, require co-operative inter-relationships in the exercise of their functions. The Constitution under the Bill of Rights, Article 43 recognizes that access to safe and sufficient water in adequate quantities simultaneously with clean and health environment a basic entitlement. The provision of water and sanitation services and the implementation of national policies on natural environment are two such key roles and responsibilities bestowed on the County Government under CoK 2010. This includes addressing the challenges of water governance including the problems of water shortage, flooding, drought, and water related epidemics that are experienced across the country. In guaranteeing these rights the constitution provides a platform for the development of adaptation and mitigation policies, strategies and legislations by itself, and in furtherance to water and sanitation service objectives.

##### **4.3.2. Vision 2030**

Sessional Paper Number 10 of 2012 entrenches Kenya Vision 2030 as the long term development strategy for Kenya. The Kenya Vision 2030 aims to transform Kenya into a modern, globally competitive, middle income country providing a high quality of life to all its citizens. The broad key priority areas of the Second Medium Term Plan (MTP II) of Vision 2030 include:

- employment creation,
- development of human resource through expansion and improvement in quality education,

- health and other social services,
- reducing the dependence of the economy on rain fed agriculture through expansion of irrigation;
- higher investment in alternative and green sources of energy;
- improving the economy's competitiveness through increased investment and modernization of infrastructure;
- Increasing the ratio of saving, investment and exports to GDP.

The Vision 2030 has therefore incorporated and entrenched measures for climate change adaptation and mitigation.

#### **4.3.3. Water Policy and Water Act 2016**

The Sessional Paper No. 1 of 1999 on the national policy on water resources management and development took cognizance of multiple use of water as a way of providing opportunities for poverty alleviation. Towards effective implementation of these strategies it created the need for an effective institutional framework to achieve systematic development, and general management of the water sector. The water resource management authority<sup>10</sup> was established to support judicious use of resources through effective management of river basins and contribute to soil and water conservation innovations. Furthermore, the policy recognized the role of rural communities living in critical catchments and gives them an essential part in decision-making. The policy was operationalized in most parts by the Water Act of 2002. The succeeding legislation Water Act 2016 aligns with the Constitution of Kenya 2010 in regard to water rights, and consolidates the gains over the past 15 years of the Water Sector reforms which include;

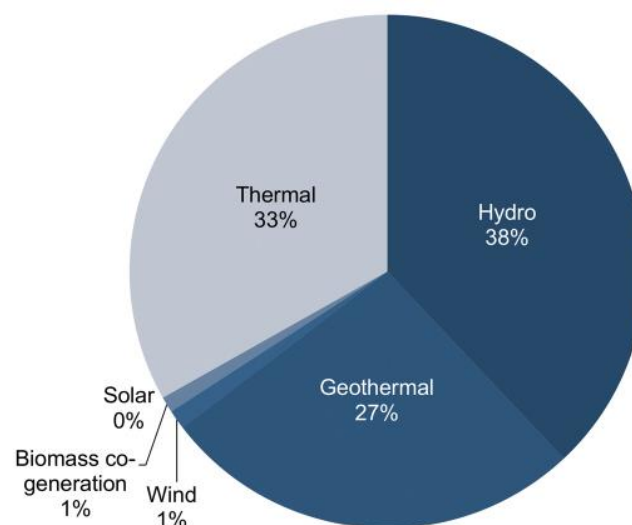
- Subsidiarity and decentralization – In line with the government's overall decentralization policy, decisions in the water sector are made at the lowest appropriate level, making sector institutions more autonomous. For example, water utilities have been transformed into autonomous, registered and regulated shareholder companies, owned by the counties.
- Separation of service delivery, policy formulation and regulation to achieve higher efficiency and transparency.
- Increased equity achieved by aligning the sector with the human right to water and sanitation and by adopting a pro-poor approach in sector policies and strategies.
- Transparency and accountability measures include efforts by sector institutions reporting regularly to the public and by stronger enforcement of regulations and complaint mechanisms.
- The participation and empowerment of water users and consumers through Water Resources Users Association (WRUAs) and Water Action Groups (WAGs) and mechanisms such as public hearings at community level.

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<sup>10</sup> *Renamed Water Resources Authority in the Water Act 2016*

#### 4.3.4. Green Economy Strategy and Implementation Plan

The National Climate Change Response (2010) and green growth Strategies (2015) both aim at enhancing the integration of climate concerns into development priorities. The strategies and the national climate change action plan (NCCAP) of 2013 sets out to guide a low carbon climate resilient development pathway. The strategies and plan encourage people-centred development to achieve sustained economic growth, enhance social inclusion, improve human welfare and create opportunities for employment and decent work for all, while maintaining the healthy functioning of the Earth's ecosystems. The Kenya Green Economy Assessment Report launched by UNEP in 2014 concluded that Kenya is already



**Figure 7: Installed electricity generation capacity as of April 2015 (GIZ, 2015)**

implementing various green economy approaches and policies, and that a transition to green economy has positive impacts in the medium and long term across all the sectors of the economy. It is anticipated that green growth path will results in faster growth, a cleaner environment and high productivity by 2030, relative to the business as usual growth scenario.

As part of this process, policy and regulatory frameworks in favour of renewable energy technologies (RETs) have been put in place. The draft Energy Bill (2015) commits the Ministry of energy and petroleum to promote renewable energy (RE) resources and to map resource potential and update regularly to keep investors informed (MoEP, 2015). Kenya's Intended Nationally Determined Contributions (INDCs) set a target to abate its GHG emissions by 30% by 2030. This will be through increased use of REs like geothermal, solar and wind energy resources and other renewables and clean energy options. Mainstreaming of climate change adaptation in the water sector by implementing its National Water Master Plan (2014) is also one of the identified contribution and target towards achieving COP 21 resolutions.

The Technology Need Assessment (TNA) for climate change and adaptation in Kenya prioritised agriculture and water sectors noting that water is an important natural resource critical for sustainable development. The water sector is considered particularly sensitive to climate change and variability (Government of Kenya (NEMA) 2013). The TNA report recommends technology interventions for water resources, including:

- i. Increasing capture and retention of rain water through the construction of water ways, recharge of strategic bore holes and other water harvesting methods
- ii. Rehabilitation of rivers and dams to improve carrying capacity, water storage and quality

- iii. Structures and technologies to ensure availability of water during the dry season, and
- iv. Protection of water towers

The importance of functional and sustainable water storage structures is thus clearly emphasised. Kenya's (Draft) National Water Harvesting and Storage Management Policy (MW&I, 2010) proposes to raise the water storage capacity from the current 124 Mm<sup>3</sup> to 4.5 Bm<sup>3</sup>, which is equivalent to a per capita storage of 5.3 m<sup>3</sup> to 16 m<sup>3</sup> by 2025<sup>11</sup>. This will require the development of additional 340 Mm<sup>3</sup> of water storage per year, (Government of Kenya 2013).

#### **4.3.5. Climate Change Act, 2016**

This Act provides a framework for action that promotes low carbon, climate resilient development in Kenya, and is an important milestone on the country's path towards developing its economy while simultaneously reducing greenhouse gas emissions. Specifically, the outcomes will include among others:

- mainstreaming climate change responses into development planning, decision making and implementation
- promoting low carbon technologies to improve efficiency and reduce emissions intensity
- providing incentives and obligations for private sector contributions to achieving low carbon climate resilient development

Existing policies and legislation are not explicit in mainstreaming climate change in water services and water management issues. In addition, there is need for a comprehensive implementation framework and funding structure to ensure that investments achieve both water services improvement while at the same time addressing climate vulnerability across different agro-ecological regions.

#### **4.3.6. Institutional framework**

The Ministry of Environment and Natural Resources (MENR) is responsible for the management of climate change response in the country through the National Climate Change Secretariat (NCCS). The NCCS leads the development and implementation of climate change policies, strategies and action plans. These include the National Climate Change Action Plan (2013-2017) which implements the National Climate Change Response Strategy (2010). The Ministry of Water and Irrigation facilitates sustainable management and development of water resources for national development for climate change mitigation and adaptation in consistence with the water sector strategies.

The Ministry of Planning and National Development is leading in the process of mainstreaming climate change into national plans including the mid-term plans under the vision 2030. Environment and Climate Change Units have been established in all sectors that are highly vulnerable to climate change. The Environment and climate change unit is expected to tackle the issue of climate change at national and county level in light of concurrent jurisdiction for environmental conservation across both levels.

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<sup>11</sup> Assuming population of 55 million by 2025 4.5 Bm<sup>3</sup> translates to 88m<sup>3</sup> per capita storage

Water Services Trust Fund (WSTF) is a state agency with a mandate to mobilise finance for the provision of water services to the underserved areas in Kenya. WSTF's strategic objective of "financing sustainable water and sanitation services in underserved rural and urban areas" (WSTF, 2014) contributes to national climate change priorities and planned development programs in the water and environment sector in Kenya.

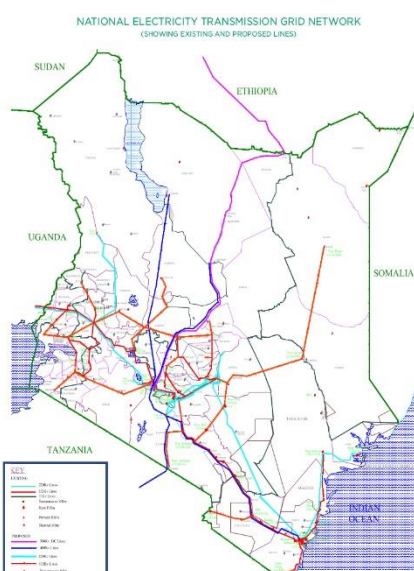
#### 4.4. Development of low cost-technology

##### 4.4.1. Small Water storage

The National Water Master Plan (NWMP) 2030 addresses the water resource management challenges in Kenya, and sets out plans to support the realisation of Vision 2030. The NWMP anticipates the development of a total of 17,860 small dams and water pans adding an additional 893 Mm<sup>3</sup>. The preliminary target of the Technology Action Plan (TAP) for adaptation is to increase water storage capacity to 4.5 Bm<sup>3</sup> and to construct 100,000<sup>12</sup> community surface rainwater harvesting systems, each with a capacity of about 30,000 m<sup>3</sup> in ASAL areas between 2015-25 (Government of Kenya 2013).

In 2015, a total of 647 water pans and 54 small dams with a potential capacity of 16 Mm<sup>3</sup> and valued at Ksh 3.5 billion, , were constructed in the arid and semi-arid and rural areas by the Ministry of Water and its agencies (Ministry of Environment and Natural Resources, Kenya n.d.). This excluding investment by other governmental and non-governmental entities. This underlines the importance of water pans and small dams in Kenya's water development. Water harvesting offers under-exploited opportunities for enhancing water security in dry lands. It works best in precisely those areas where rural poverty is most prevalent. When planned well, water harvesting has the potential to simultaneously reduce water scarcity and poverty, as well as to improve the resilience of the environment (Rima & Hanspeter, 2013).

##### 4.4.2. Electricity coverage and off-grid potential in Kenya



**Figure 8: National Electricity transmission Grid,** (Kenya Power & Lighting Company Limited, 2013)

Kenya's electrification rate was about 23% in 2011, with rural energy access to the grid about 7% and urban access at 50%, and the electricity demand is growing by 5-8% per annum, (Hille & Franz, 2011). Kenyan Government is working to rapidly increase electrification rates in both urban and rural areas as part of its national Vision 2030 and aim to raise rural electricity access to an ambitious 40% by 2024.

However, the overwhelming priority right now is to expand large-scale capacity in pace with economic growth, maintaining an adequate reserve margin. Figure 8 shows the current (red colour) and proposed (purple, deep and light blue) network expansion which shows that eastern and northern parts of Kenya will not be covered adequately, not even by 2030. Therefore small-

<sup>12</sup> 15,000 water pans of 30,000m<sup>3</sup> each are required to achieve 4.5Bm<sup>3</sup> water storage by 2025 which compares to the 2030 waster master plan of 17, 860 by 2030. 100, 000 in 15 years seems unrealistically high

scale renewables also have a role and potential in achieving off-grid access and modern pumping energy for water supplies.

## Summary

- a. The annual per capita freshwater endowment estimated at 427 m<sup>3</sup> in 2016 meaning water is chronically scarce.
- b. The current population of 47.3 million people is roughly distributed according to rainfall endowment, which underscores the importance of reliable water supplies for economic development and livelihoods.
- c. Climate change and variability contribute to a multitude of immediate and long-term impacts on water resources in Kenya and on sustainable economic growth.
- d. An increased incidence of droughts under climate change is likely to increase rural-urban migration and confound urban vulnerability, and addition drought cycles have become shorter, reducing over the years, from every 5-7 years to every 2-3 years.
- e. Yet, despite the paramount risks of climate change, the water sector in Kenya has not explicitly addressed climate change issues. It is therefore important and urgent to explicitly operationalize a framework of climate impacts mitigation and adaptation including coordination and financing structures.
- f. It is important to note that the Kenya's water policy (1999) is outdated and therefore they do not critically address the issue of public private partnership. The current policies view water as service as opposed to an investment.
- g. To increase the storage capacity it is necessary to harness surface rainwater through the development of storage infrastructure such as small dams and water pans.
- h. Further, to enhance water coverage and especially in rural and peri-urban areas, it is important to integrate the use of off grid systems for sustainable water supply. Off-grid electricity and small water storage structures have an important role in medium and long-term water development.

## 5. Overview of the Selected Green Low Cost Technologies

*This chapter describes the application of the selected green water technologies in Kenya: Solar and wind pumping system and water pans, and further outlines the key strengths and weaknesses of each technology.*

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### 5.1. Background

A broad range of low carbon energy technologies have been disseminated in Kenya and generally in Africa, with varying levels of success. For a long time, the use of solar and wind energy resource has been hindered by low levels of awareness of the benefits, lack of reliable data and information for planning, high technology cost and proliferation of sub-standard technological equipment. The use of solar PV and wind systems have been perceived to be inferior technologies compared to conventional technologies due to high installation costs and lack of technical skills. (Tracy, Jacobson, & Mills, 2010), (GoK Ministry of Energy and WinDForce, 2013), (AHK, 2013). Based on experience from Eastern Africa with the Kijito wind pumps (Harries, 1997) (Kamp & Vanheule, 2015), the following factors affecting dissemination of wind pumps have been identified:

- Remoteness of areas of installation making access and communication difficult
- Security challenges
- Conflicts of different groups served by one water source
- Little or no experience of communities in handling technology
- Laxity in maintenance
- Lack of confidence in the technology

A report by GIZ (2015) identifies similar concerns and emphasized the need to address them in order to promote wind energy in Kenya. In addition supply of auxiliary equipment and related services, technical knowhow, land acquisition and long term policy stability were also found to be key parameters. Studies found that that government subsidies, tax exemptions and financing both for suppliers /manufacturers and consumers are some of the initiatives that may speed up the uptake of wind mills for water supply in remote underserved areas (Harries, 1997). Both solar and wind systems have considerable growth potential for water supply in the following reasons:

- many areas especially in the ASAL are not served by grid and therefore an off grid system application offer immediate access to electricity;
- diesel pumping system is an expensive technology to operate and maintain and contributor of GHGs and noise pollution;
- many underserved areas have good potential for ground water but require energy to extract from below ground;
- there is adequate irradiation throughout Kenya;
- wind speeds are sufficient in most places good for small turbine wind energy generation;
- Low maintenance cost
- Low cost green technology are environmental friendly and largely improves climate resilience of



water investments

- Low operations cost, example no fuel cost

### 5.1. Solar energy

It is estimated that 70% of the land in Kenya has an annual solar energy potential of about 5kWh/m<sup>2</sup>/day. 32.4% of the land has a mean yearly solar potential ranging between 5.0-5.5 kWh/m<sup>2</sup>/day, while 26.5% of the country's land area has an average yearly solar energy potential in the range of 5.5-6.0 kWh/m<sup>2</sup>/day. Furthermore, above 10.8% of the land surface area in Kenya has the potential of receiving more than 6kWh/m<sup>2</sup>/day of solar energy. There is monthly variation in the distribution of yearly solar energy potential between March and September characterised by high value of about 5kWh/m<sup>2</sup>/day. The months of October, November, and December recorded the lower values of radiation of 4.72, 4.76 and 4.14kWh/m<sup>2</sup>/day respectively, while in January, February and March the mean estimate is of 5.4kWh/m<sup>2</sup>/day.

The total installed solar power capacity is estimated at 16 MW as of 2012, the vast majority is contributed by solar home systems installed at individual homes. Figures from the Energy Regulatory commission (ERC) of Kenya show that the total installed capacity is likely to be over 20 MW as of January 2015. This is projected to grow at 15% annually. PV systems commercially distributed in rural areas in Kenya typically consist of 14 to 20 W, wiring, rechargeable battery, sometimes a charge controller system, lighting systems, and connections to small appliances (such as a radio, television, or mobile phone charging units). Most solar accessories are imported mainly from China, the United Kingdom and the US. The exception is storage batteries, which are locally manufactured (ACTS, 2015).

Estimated over 320,000 rural households (4.4% of rural people in Kenya) have solar home systems as of 2010. Annually, it is estimated that 25,000-30,000 PV systems are sold in the market. The "Over-the-counter" nature of Kenya's off-grid PV market has remained the same as it was since the 1990's, except for a few important changes, namely:

- i. Consumers have more choices and lower prices;
- ii. Technology improvements have made lower cost inverters, solar modules and pico-systems<sup>13</sup> available on the market; There are more players operating in more niches, including pumping, designed systems, portable systems and micro-grids, and this is resulting in a trend towards better systems in terms of ease in operation and maintenance (AHK, 2013).

Despite the annual solar energy potential in Kenya, installed solar PV capacity especially for water pumping is still low in the country. It was initially speculated that the low uptake of solar technology was associated with unaffordability, low levels of awareness and limitations in terms of technical capacity. The limited diffusion of solar technology can be attributed to a wide range of factors associated with players on every level of the value chain, from the end user to the investors (Silva n.d.). Hence, various factors affect the choice and penetration rate of PV lighting systems in rural Africa,

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<sup>13</sup> A Pico PV system is defined as a small PV-system with a power output of 1 to 10W, mainly used for lighting and thus able to replace unhealthy and inefficient sources such as kerosene lamps and candles

including access to finance, distribution challenges, consumer education, and market spoilage due to substandard products, government policies and after sale support. Strengths and weaknesses described in Table 10 below.

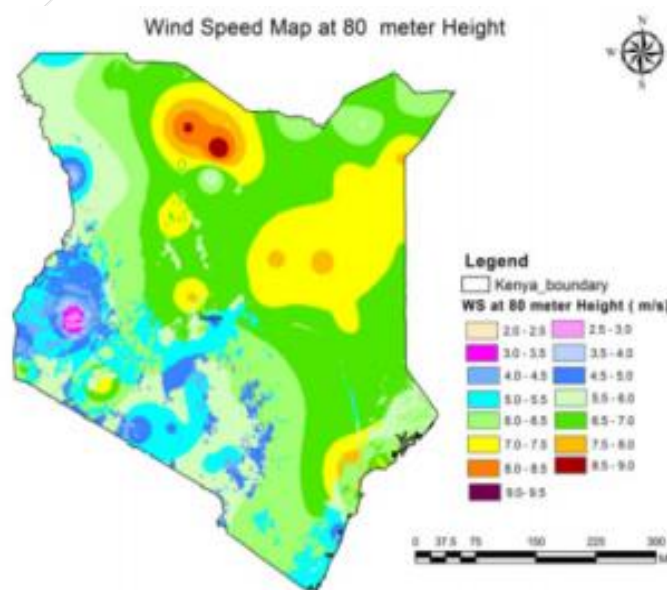
**Table 10: Strengths and weaknesses of PV energy systems, (UNIDO, 2010)**

Strengths	Weaknesses
Technology is mature. It has high reliability and long lifetimes (power output warranties from PV panels now commonly for 25 years)	Performance is dependent on sunshine levels and local weather conditions
Automatic operation with very low maintenance requirements	Storage/back-up usually required due to fluctuating nature of sunshine levels/no power production at night.
No fuel required (no additional costs for fuel nor delivery logistics)	High capital/initial investment costs
Modular nature of PV allows for a complete range of system sizes as application dictates	Specific training and infrastructure needs
Environmental impact low compared with conventional energy sources	Energy intensity of silicon production for PV solar cells
The solar system is an easily visible sign of a high level of responsibility, environmental awareness and commitment	Provision for collection of batteries and facilities to recycle batteries are necessary
The user is less affected by rising prices for other energy sources	Use of toxic materials in some PV panels

## 5.2. Wind Energy

The potential for wind generation in Kenya is one of the highest in Africa with a total of 346W/m<sup>2</sup>. The mean wind speed in most part of Kenya reaches over 6 m/s, with the areas surrounding Lake Turkana (over 9 m/s) and the coast (5-7 m/s) being attractive for wind power generation. There are between 10-20 locations with wind speeds greater than 7 m/s. With middle to large wind turbines, a total of over 1 GW could be achieved.

For close to a century, mechanical wind energy has been used in Kenya for water lifting. Electric wind power generation was introduced in the country in 1984 with a grant from the Government of Belgium for two turbines: a 400 kW turbine (effective 350 kW) installed at Ngong Hills and connected to the grid and a 200 kW turbine in hybrid with a diesel engine in Marsabit



**Figure 9: Wind Speed Map of Kenya at 80m height**

town (AHK, 2013). Starting in March 2007 a wind rural electrification project with the installation of a 1-kW wind turbine for battery charging has been implemented for schools in off-grid areas, as part of national effort to light-up all public schools.

The small wind energy systems market in Kenya is dominated by 12 companies listed in Table 11, six local manufacturer and 6 dealers who import their products (Rencon Associates and JICA, 2013). The turbines in the market have varying capacity ranging from 200W to 12 kW and cut in wind speed of 2-4 m/s.

Since the late 1970s mechanical wind pumps going by the name *kijito*<sup>14</sup> had been installed in the Kenya, largely in ranches and remote communities with one local integrator (Bobs Harries Engineering Ltd) dominating the market. The technology had been introduced in 1975 by Intermediate Technology Development Group from England with the goal to develop a commercial, modern and reliable windmill ("The WOT-field," 2002). Kijito wind pumps were produced in 5 rotor sizes ranging 3.65m - 7.9m to offer wide range of technical solutions both for deep water sources and high water needs. The multi-bladed rotor generates high torque for improved performance even in low wind regimes. For example, a 20ft (6m) rotor can provide 113 m<sup>3</sup>/day in 4-5 m/s wind speed at a 20m head provided no serious obstacle to the wind flow is located within 100m of the installation, ("Wind Pumping," n.d.)

Table 11: Dominant small wind market players in Kenya , (Rencon Associates and JICA, 2013)

	Name	Main Wind Energy Product	Source of Product
1	Kijito Windpower Ltd	Wind mills	Own manufacture
2	Davsan Engineering Works	Wind mills	Own manufacture
3	Kigima Hightech Metal Works	Windmills	Own manufacture
4	Craftskills Wind Energy International Ltd	Wind Turbines	Own manufacture
5	Powergen Renewable Energy Ltd	Wind Turbines	Own manufacture
6	Riwik East Africa Ltd	Wind Turbines	Own manufacture
7	Davis & Shirtliff Ltd	Wind turbines	Imported
8	Chloride Exide (K) Ltd	Wind turbines	Imported
9	Powerpoint systems (E.A.) Ltd	Wind turbines	Imported
10	Access Energy Ltd	Wind turbines	Imported
11	Kenital Kenya Ltd	Wind turbines	Imported
12	Trusun Power Ltd	Wind turbines	Imported

Continued use of wind energy declined with the arrival of oil fired internal combustion engines, which are flexible and more convenient to use. However, the rising cost of oil is making exploitation of wind energy attractive again, because it is cheaper in the long run and more convenient particularly in areas remote to grid and oil supply outlets. Engine driven pumps are uneconomical at very low requirements, also due to the fact that diesel pumps are not made for power ratings below 2 kW.

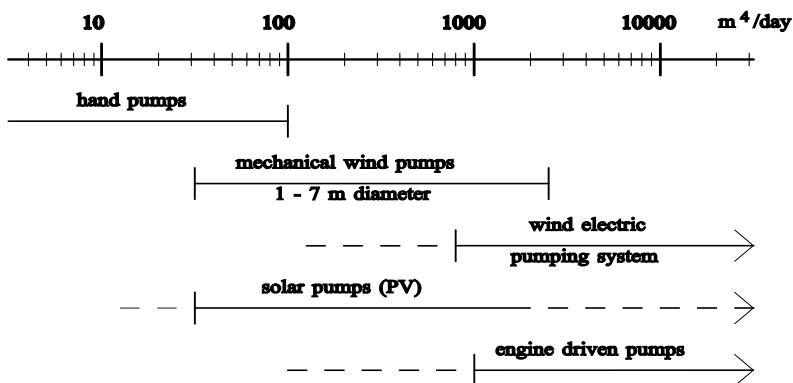
The niche for wind pumps in water supply range from 20 m<sup>4</sup> to 2000 m<sup>4</sup>/day.<sup>15</sup> The corresponding rotor diameters range from 1 to 7.5 meters. The merits of a wind pump can be viewed as serving a multitude of users against low energy inputs. For instance a 3 m diameter wind pump can supply 30m<sup>3</sup> water per day (average per year) at a pumping head of 10 m with a very moderate average wind speed of 3.5 m/s. This will serve a village with 750 people (assuming 40 l/d per capita) despite the average power delivered being only 34 Watts<sup>16</sup>.

<sup>14</sup> *Kijito is Swahili name for small river*

<sup>15</sup> *m<sup>4</sup>/day is a measure of power required to pump a certain amount of water over height -it's a product of flow (m<sup>3</sup>) and head (m)*

<sup>16</sup> *Power produced by wind turbine is calculated using the equation  $P_M = \frac{1}{2}C_p\rho AV^3$ , where,  $P_M$  is power (in watts) available from the machine,  $C_p$  is the coefficient of performance of the wind machine,  $\rho$  is the air density in kilograms per cubic metre (kg/m<sup>3</sup>),*

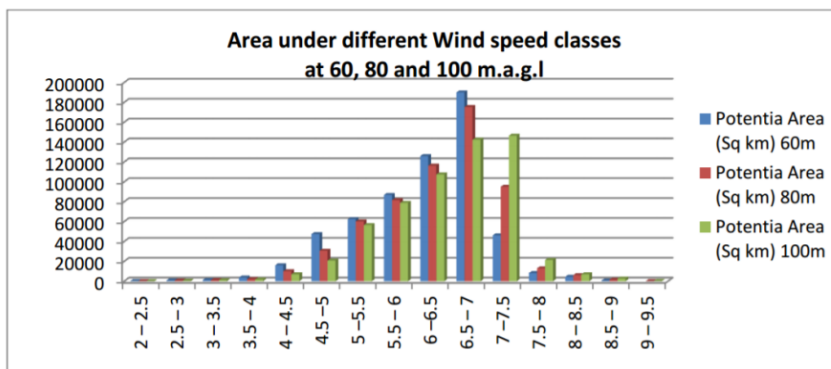
Examining the niches for the various pumping options in Figure 10 one sees clearly that hand pumps are the obvious solution at the lower end of the and are used up to 100m<sup>4</sup>/day, but there known cases where wind pumps are used for energy requirements down to 20 m<sup>4</sup>/day.



**Figure 10: The wind pumping niche versus other pumping**

The range of mechanical wind pumps is limited by rotor size, from about 1 to 7.5 m diameter. At larger power demands it is more convenient and economical to generate electricity which can be used to drive a motor/pump combination. These are indicated as Wind Electric Pumping Systems (WEPS). Especially at sites with high wind speeds ( $\approx 5$  m/s), they are attractive from diameters of 3 m and up.

Despite the remarkable potential for wind energy expansion in Kenya, several challenges still remain. Lead to slow adaptation of small wind turbine in rural and peri-urban areas. These include the cost of technology, site selection, lack of a wind resource data base, aesthetic, noise and vibrations, low awareness and lack of local capacities to operate and maintain these systems. Strengths and weaknesses of wind energy systems described in table 10 below.



**Figure 11: Comparative Analysis of Wind speed at 60m, 80m and 100m, (GoK Ministry of Energy and WinDForce, 2013)**

$A$  is sweep area in m<sup>2</sup> and  $V$  is the mean annual windspeed in m/s. Considering that a wind turbine will only operate at maximum efficiency for part of the time due to variations in wind speed. A rough estimate of the average annual power output ( $P_A$ ) from a windpump is given  $P_A = 0.1 A V^3$ .

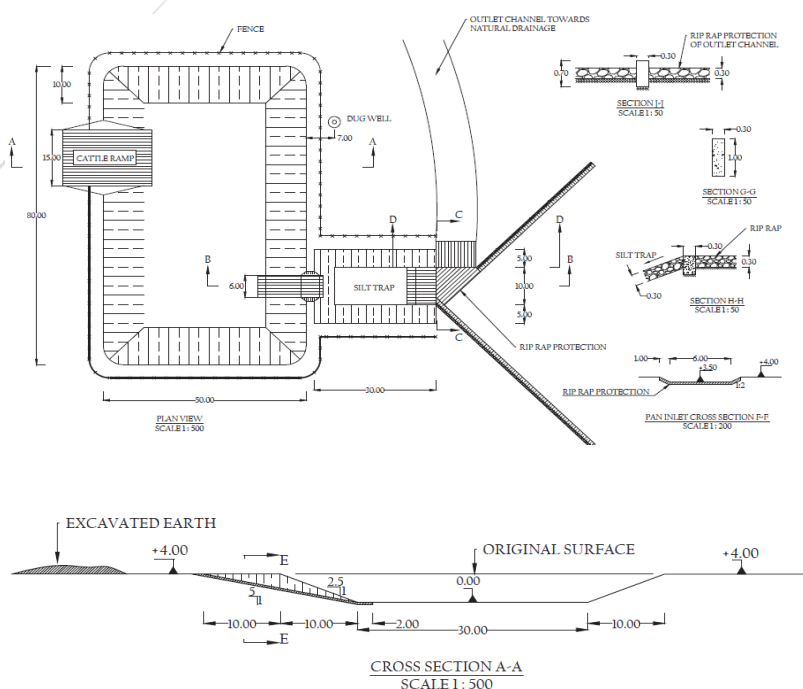
**Table 12: Strengths and weaknesses of wind energy systems, (UNIDO, 2010)**

Strengths	Weaknesses
Technology is relatively simple and robust with lifetimes of over 15 years without major new investment	Site-specific technology (requires a suitable site)
Automatic operation with low maintenance requirements	Variable power produced therefore storage/back-up required.
No fuel required (no additional costs for fuel nor delivery logistics)	High capital/initial investment costs can impede development (especially in developing countries)
Environmental impact low compared with conventional energy sources	Potential market needs to be large enough to support expertise/equipment required for implementation
Mature, well developed, technology in developed countries	Craneage and transport access problems for installation of larger systems in remote areas
The technology can be adapted for complete or part manufacture (e.g. the tower) in developing countries	

### 5.3. Surface Water Storage Pans

Water storage pans are excavated surface water storage facilities of limited capacity which are mainly constructed in locations where the topography does not allow the construction of a small dam and instead favours excavation. Excavation of larger pans (up to 150,000 m<sup>3</sup>) is possible and can be done, especially near populated centres, but the construction cost is generally high due to the 1 to 1 excavation to storage ratio.

Pans are excavated below the natural ground level, and with the exception of pans constructed on inclined locations, the volume of earth excavated will be equal to the storage capacity of the pan and therefore when compared to a small dam, the water to earth ratio (water storage volume / earth excavated volume) is low. However, when a suitable inclined location can be identified for the construction of the pan a somewhat more favourable ratio



**Figure 12: Typical plan and section drawing of a water pan, (Government of Kenya, 2015)**

can be obtained. Storage pans tend to be relatively expensive constructions when compared to small earth dams; where possible natural depressions can be enlarged to produce water pans with a slightly better storage to earthworks ratio. (Government of Kenya, 2015)

Pans for the purpose of surface water storage can be constructed wherever a sufficient quantity of water can be intercepted to create a small reservoir. Pans are basically used in such locations where no topographically suitable site can be found for the construction of a small dam, or where no suitable construction materials for the construction of a dam can be found.

Water storage pans are subject to the same limitations regarding sedimentation and evaporation as small dams. Due to their shallow depths (usually 2.50 m to 5.00 m) water storage pans are usually not suitable as permanent water sources because of high evaporation areas. In catchment areas subject to erosion, silt traps will have to be included in the design (Government of Kenya, 2015).

Apart from the two factors mentioned above (topography and availability of construction materials), the basic principles for selection of appropriate locations include:

- The water-tightness of the reservoir in sandy areas but since pan dimensions are limited, lining of the reservoir with an impervious clay blanket can often present a solution for pans,
- The natural drainage and flow pattern of the intercepted water and an overflow structure for any excess water towards the natural drainage
- Silt trap which is often combined with the overflow structure.
- Sedimentation, evaporation and ecological impact
- Specific alignment of the pan to minimize earthworks
- Storage sizes considering the expected inflows, length of the dry period, reliability level to be maintained during a given dry period and the expected water use and relative importance of the evaporation losses<sup>17</sup>.

Water harvesting through the development of water storage pans offers under-exploited opportunities for enhancing water security in drylands and works well in the areas where rural poverty is relatively high. When practiced well, water harvesting has the potential to simultaneously reduce water scarcity and poverty, as well as to improve the resilience of communities to climate change (Rima & Hanspeter, 2013). Table 13 shows the various strengths and weaknesses attributed to water pan as a storage technology.

**Table 13: strengths and weakness of water pans**

<b>Strengths</b>	<b>Weaknesses</b>
Easy to construct and maintain	Low, erratic rainfall and droughts may result to water pans drying

<sup>17</sup> Generally pans in arid areas should be sized with emphasis on availability of grazing (i.e. the pan should dry out just as the available grazing is finished). Large pans may result in overgrazing in the area around the pan.

No energy is required to draw water	Elevation often restricts conveyance by gravity
Less susceptible to damage when overtopping and weak structural foundation	Seepage losses from the reservoir
Reduces impact of floods by storing initial floodwaters, controlling erosion.	Poor water quality owing to high turbidity and contamination of water in open reservoirs
Can be constructed on any soil type	High rate siltation by sediment during severe storms, and especially at the end of dry season
It has potential of raising water table downstream and in nearby wells.	The risk of people and livestock drowning in the pool
	High evaporation losses
	Expensive to construct relative to water volume stored

## Summary

- i. Water pans, wind and solar pumping have been disseminated in Kenya with varying levels of success, but all the three technologies have considerable potential for growth and applications in water supply. Key supporting factors include:
  - Water scarcity and low borehole yield in some areas
  - High incidences of ground of water salinity which renders water not suitable for livestock and irrigation
  - Land availability and social cohesion in rural areas
  - Rural areas especially in the ASALs are not served by grid and therefore an off grid system application offer immediate access to electricity;
  - Diesel pumping system is an expensive technology to operate and maintain and contributor of GHGs and noise pollution;
  - Many underserved areas have good potential for ground water but require energy to extract from below ground
  - There is adequate irradiation throughout Kenya;
  - Wind speeds are sufficient in most places good for small turbine wind energy generation;
  - Low cost green technology are environmental friendly and largely improves climate resilience of water investments
- ii. Despite the remarkable potential for low-carbon in Kenya, several challenges are cited for their slow adaptation in rural and peri-urban areas. These include the low levels of awareness of the benefits, site selection, and lack of reliable data and information for planning, aesthetic, noise and vibrations, as well as high technology cost and sub-standard technology and lack of local capacities to operate and maintain these systems.







## 6. Capacity, Prevalence and Functioning of Technologies

*Based on analysis of the data collected in the targeted sites, this chapter presents the findings pertaining to (i) the **reliability** of the selected technologies to perform required functions steadily under different ecological zones; (ii) the **capacity** to meet water demand for households and other intended uses, and (iii) the **durability** of these technologies to meet water demand.*

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### 6.1. Prevalence of Wind, Solar and Water Pans

Communities in most technology sites surveyed had a previous experience with different water supply technologies namely diesel systems, grid electricity, solar systems, wind systems, earth dams, sand dams and water pans. The technologies varied in materials used, size and implementers. 70% of technology installations surveyed were less than 10 years old and in half of the cases; elevated storage tanks were utilized alongside as a form of water back-up scheme.

It is evident from the spread of technologies that (Table 14) humid, sub-humid and semi-humid regions rely more on surface streams. Small gravity flow network have been developed to serve urban areas in particular. In the humid and sub-humid areas the use of surface streams and shallow wells make up are dominant source of in the semi-humid to semi-arid areas. Boreholes are prevalent in the semi-arid and arid areas as a result of the lack of reliable surface flow. In Baringo County for example the use of boreholes is at 82.4% all of water sources in arid areas compared to 16.7% in the semi-humid areas. There are many water-pans and small water storage structures in all the four counties. Water pans are common in semi humid to arid areas, accounting for 25% of water sources in Embu, 40% in Baringo, 75% in Homabay and 60% in Isiolo but, few water pans actually work throughout the year. Water pans were preferred over boreholes due to ground water salinity. Water-pans were initially intended to address livestock water demand but presently they are also utilised for domestic uses, due to a lack of alternative sources. In humid and semi-humid areas of Baringo, Embu and Homabay small storage dams are found, although not many are used for small water storage.

**Table 14: Distribution of water sources type by Ecological Zone per County**

Ecological zone		County				Frequency	Percent of Total
		Embu	Baringo	Homabay	Isiolo		
Humid	Shallow wells	1				1	1.4%
	River	2				2	2.7%
Sub-Humid	Small dam		2			2	2.7%
	River	1				1	1.4%
Semi-Humid	Borehole	1	1	4		6	8.2%
	Water Pan			1		1	1.4%
	River	1				1	1.4%
Semi Humid to Semi-Arid	Borehole	10	1	8	2	21	28.8%
	Shallow wells	1		2		3	4.1%
	Water Pan	1		3		4	5.5%
	Small dam	4				4	5.5%
	River			2	1	3	4.1%
	Others	3				3	4.1%
Arid	Borehole		14		3	17	23.3%
	Water Pan		2			2	2.7%
	River		2			2	2.7%
Grand Total		25	22	20	6	73	100%

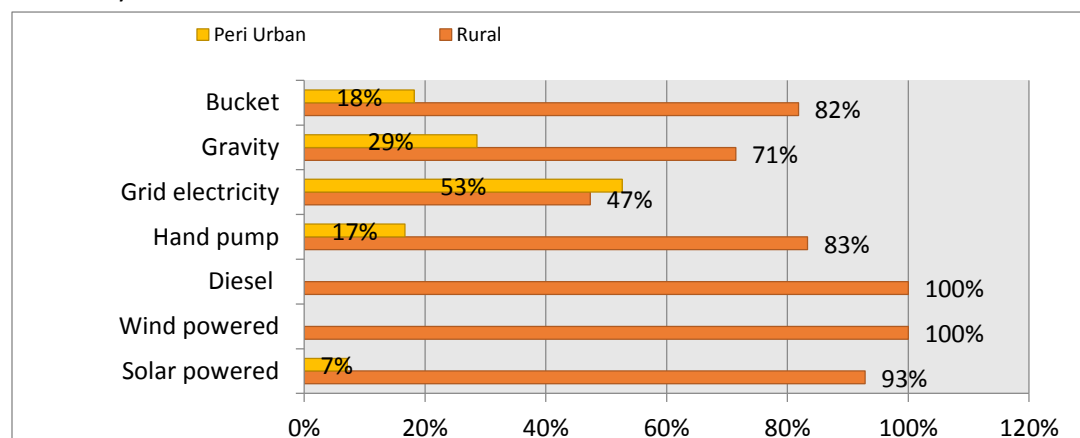
The static level of boreholes is relatively deep ranging from 60 to 200m meters deep creating a need for abstraction energy. There is great dependency on fuel and electricity subsidies from the county government, and partly for this reason, many borehole are non –operational for significant periods in the year. Since solar is often matched with boreholes, uptake of solar technology is limited in humid and semi-humid areas. Conclusively, the high cost of maintaining diesel pumps and generators is a strong motivation in favour of solar PV. The data collected in the field show that solar PV is used across all the ecological zones, but predominant in arid and semi –arid which account for 80% of all solar installation observed. In comparison, solar energy for water pumping accounts for 10% in humid areas, 7% in sub humid and 3% in semi-humid areas.

Table 15 shows an accelerated uptake of solar energy for water pumping after year 2000 onwards. The prevalence of solar installations is generally lower in Embu because most water supplies especially in the highlands depend on gravity flow from perennial rivers. The few solar installation observed during the survey were located in the semiarid areas of Mwea and Mavuria.

**Table 15: Distribution of the target technologies by year of installation per county**

		Abstraction Method							Water pans & small dams	Total	
		Solar	Wind	Diesel	Hand pump	Grid electricity	Gravity	Bucket			
County											
Embu	1970-1979										
	1980-1989		1		2	1		1		5	
	1990-1999		1			1	1		1	4	
	2000-2009	1	1	1		1	3	3	1	11	
	>=2010	1		2	2	2	1	1	2	11	
	Total	2	3	3	4	5	5	5	4	31	
Baringo	1970-1979			1			1			1	
	1980-1989										
	1990-1999					2				2	
	2000-2009	2		5		1		1	1	9	
	>=2010	5	1	1		2	1		6	15	
	Total	7	1	7		5	2	1	7	27	
Isiolo	1970-1979					1				1	
	1980-1989										
	1990-1999	1		2		0				3	
	2000-2009	1		0		3			3	7	
	>=2010	9		1		1			5	16	
	Total	11		3		5			8	27	
Homa Bay	1970-1979								1		
	1980-1989							1		1	
	1990-1999			1						1	
	2000-2009		1	1	1	1		1	1	5	
	>=2010	7			1	2		3	2	15	
	Total	7	1	2	2	3		5	4	23	
Total Installation s by year in all the counties	1970-1979			1		1	1		1	4	3.36%
	1980-1989		1		2	1		2	0	6	5.04%
	1990-1999	1	1	3		3	1		1	10	8.40%
	2000-2009	4	2	7	1	6	3	5	6	34	28.57%
	>=2010	22	1	4	3	7	2	4	15	58	48.74%
	Total	27	5	15	6	18	7	11	30	119	100.00%
	%age abstraction energy source	30.3%	5.6%	16.9%	6.7%	20.2%	7.9%	12.4%			

Figure 13 shows the distribution of water abstraction methods across rural and peri-urban areas. In peri-urban areas the use of green technologies has not been widely adopted; for example only 70% of solar pinging installations were found in peri-urban areas. The use of grid electricity is predominant source of abstraction energy probably because peri-urban areas in the four counties are well connected to grid electricity hence ease access.



**Figure 13: Distribution of water abstraction methods in rural and peri-urban areas**

Table 16 and Table 17 compare water abstractions methods by ecological zones based on responses given by water users and managers respectively. Solar is the predominant water abstraction method evidenced by 29% of the water users and 30.8% of water managers. The use of electricity for water abstraction water is proportionate to the use of solar systems, with 21.7% of the users and 20.9% of water managers indicating to use it for water pumping. In contrast, 10.1% of the users indicated to use diesel against 16.9% installation indicated by the water managers. This contrast can be linked to the widespread complaints expressed by users about diesel engines' downtime because of lack of fuel and constant equipment breakdowns. 32.6% of the users indicated to use hand pumps and buckets respectively to abstract water. 18.3% of the technology points were using buckets and hand. This implied that users reverted to manual methods whenever modern methods of abstraction failed.

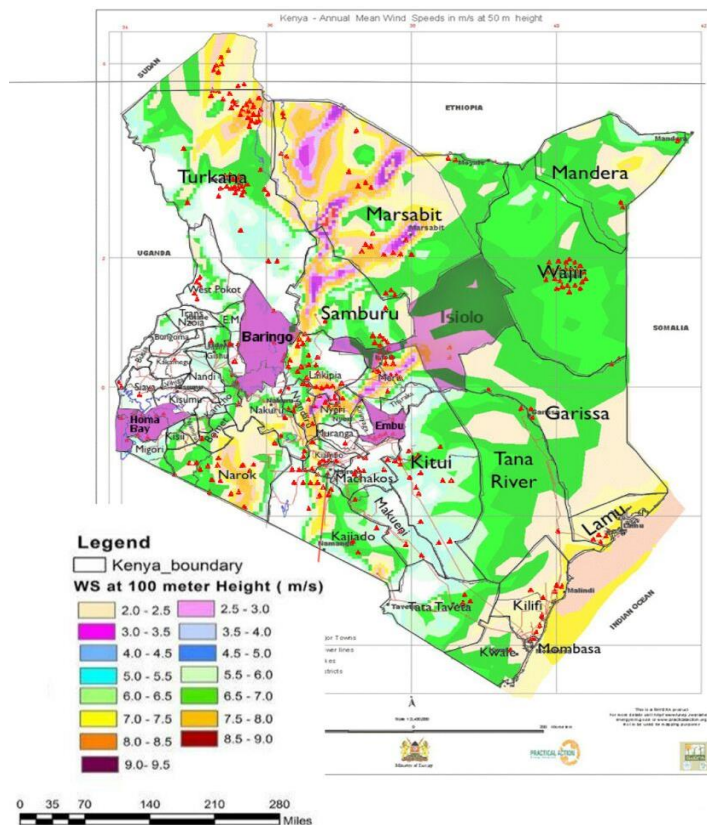
Water Abstraction Technology	Humid	Semi-humid to semi-Arid	Semi-humid	Arid	Frequency	Percent of Total
Solar pumping		13	6	21	40	29.0%
Diesel pump		8	2	4	14	10.1%
Wind pumping		1			1	0.7%
Grid electricity		14	1	1	16	21.7%
Hand Pump		16			16	11.6%
Gravity		1	1	6	8	5.8%
Bucket	1	20	1	7	29	21.0%

<sup>18</sup> The same question on the primary method of water abstraction was asked to both the technology points managers and users and the responses compared

**Table 17: Distribution of water abstraction methods by ecological zones by water managers<sup>19</sup>**

Technology type	humid	sub humid	Semi Humid	Semi Humid to Semi-Arid	Arid	Frequency	Percent of Total
Solar powered			3	8	17	28	30.8%
Wind powered				4	1	5	5.5%
Diesel			1	5	9	15	16.5%
Hand pump				6		6	6.6%
Grid electricity	2	2	2	9	4	19	20.9%
Gravity	1	1	1	2	2	7	7.7%
Bucket			1	9	1	11	12.1%

Only five wind energy installations were observed in all the four counties; three in Embu, one in Baringo and one in Homabay. Four of the five were mechanical wind system installed prior to 2009, while the fifth is a wind electric system installed in 2012 in Baringo. Only one out of the five wind systems was functional at the time of the field visit, although users indicated it could not pump water to long distances and therefore grid electricity was used to supplement water abstraction.



**Figure 14: Distribution of Kijito Mechanical wind pumps in Kenya**

wind velocity 4m/s at 50m height. Considering the average height of the tower is 14.25 meters, it is probable that the wind speed is lower at the installed height due to ground obstruction.

The observed wind mechanical systems were installed by Bob Harris Ltd. Interview with the supplier confirmed that the company had installed 347 systems in Kenya since late 1970's on sites shown in Figure 14. 70% of these were financed by the Catholic Church in Kenya and the rest mostly by individuals and ranches. From records provided by Bob Harris Ltd, it was found that 9 mechanical wind pumps were installed evenly across Homabay County, 6 in east Baringo, 5 around Isiolo town and Garbatulla, and 6 in lower Embu County. Most of these installations have been replaced since then with solar PV. During the field study one such replacement was on-going in Lambwe, Homabay.

In the analysis, wind pump site map was superimposed over wind speed map at 50m to give an idea of prevailing wind speed on site. The wind energy installations in the four study counties - with exception of those near Isiolo town - are located in areas with poor to marginal wind potential areas, generally less than a

<sup>19</sup> Question of abstraction method by water managers

According to Bob Harris management, the greatest challenges they faced was limited data on wind speed and therefore inability to synchronise suitable site for wind pump installation. As a result of these challenges, uptake of mechanical wind systems has sharply declined in the recent past. These sentiments were shared by two other local companies, GoSolar and Centre for Alternative Technology, and no longer supply wind systems. There is in general limited experience with electric wind pumping in the country. Davis and Shirtliff, a leading supplier of pumping solution, tried small electric wind turbines with a capacity of less than 1 kW, but the installation was found to be relatively expensive due to the cost of mounting the frame.

### 6.1.1. Water-Energy Interface

Examining the interaction between water and energy all modern sources of energy, solar and wind technology had been installed to abstract water from boreholes and shallow wells. A significant 14% used buckets to abstract water from rivers, shallow wells, water pans and small dams. Considering that groundwater is the dominant water resource type in ASALs and the integration of renewable energy in water supply systems has obvious advantages for raising efficiency and commence in the ASALs.

		Borehole	Shallow wells	Water Pan	Small dam	River	Others	Totals
<b>ENERGY SOURCES</b>	Solar powered	27						<b>27</b>
	Wind powered	5	1					<b>6</b>
	Diesel	10		2	1	1		<b>14</b>
	Hand pump	4	1					<b>5</b>
	Grid electricity	10	1		2	4		<b>17</b>
	Gravity	1		1	1	3	1	<b>7</b>
	Bucket		1	6	2	1	2	<b>12</b>
	<b>Total</b>	<b>57</b>	<b>4</b>	<b>9</b>	<b>6</b>	<b>9</b>	<b>3</b>	<b>88</b>

### 6.2. Capacity to reliably meet demand

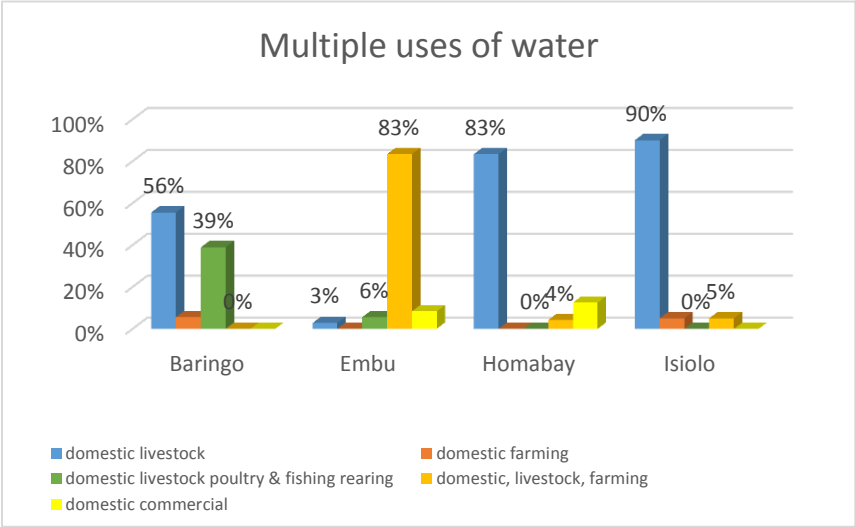
The type of water uses and related demand is a critical guide to investment decisions. The demand for water and preference of sources and technology is considered both by entitlements based on guidelines and the users' own perception of the ideal supply required for their multiple uses of water.

The technologies primarily supplied water for domestic uses at 96%, 74% of the users who used the sources for water for livestock and 28% for small scale irrigation. While water for domestic use and livestock is

Uses of water	Frequency	Percent	Percent of Users
<b>Domestic</b>	127	45.70%	95.5%
<b>Livestock</b>	98	35.30%	73.7%
<b>Poultry and fishing rearing</b>	9	3.20%	6.8%
<b>Farming</b>	37	13.30%	27.8%
<b>Commercial</b>	6	2.20%	4.5%
<b>Others</b>	1	0.40%	0.8%

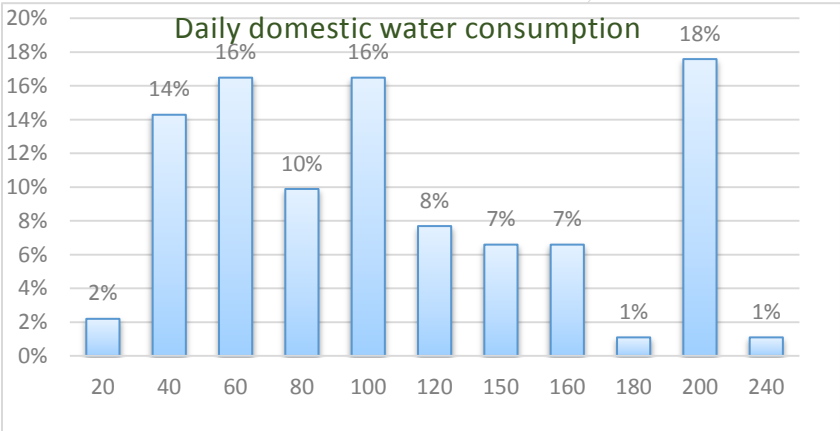
important in all the 4 counties, demand for irrigation water among water users is significant in Embu County (71.4%) and to a lesser extent in Baringo (15.4%) but marginal in the Isiolo and Homabay counties. 75 % of all users needed water for more than one use, as shown in Figure 15. The dominant

uses were livestock and domestic use in Isiolo (90%) and Homabay (83%), while 83% of multiple users in Embu utilised water for farming, livestock and domestic uses. In Baringo water supplies are used significantly for domestic livestock, poultry and fishing.



**Figure 15: Multiple uses of water per county**

The daily domestic water consumption mean in the surveyed counties is 125 litres per household per day. There is considerable regional variation in water consumption for instance Homabay and Baringo the domestic water consumption stood at 187 lpd with 80 lpd in Isiolo. 57% of all households collect between 20 and 100 litres from the nearest water point. There is unexplained sharp rise in the number of users who reported daily collection of 200 lpd Figure 16 and most of them were in Homabay County.



**Figure 16: Volume of water collected from technology sources per day**

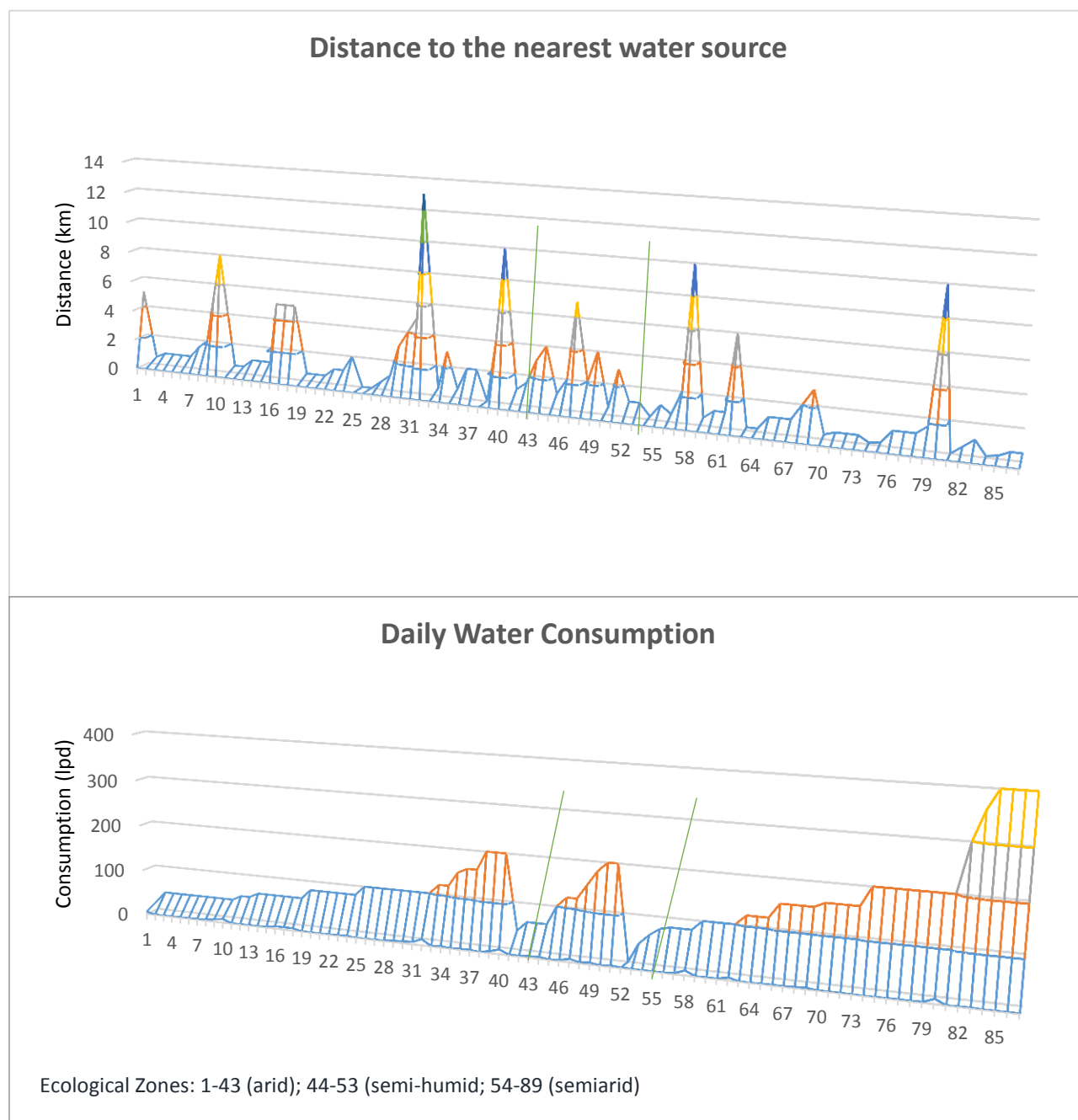
39% of water technology points were located within less than 1 km from the user households, while cumulative 62% were less than 1.5 km from where the users resided. 14% of the users’ travelled for more than 5km to collect water. The water sources were closer to users in Embu and Homabay but significantly distant in Baringo, where 88% cover more than 1 km to collect water. There is no distinction in the distance covered by user to the water point in the different ecological zones, nor is there discernible correlation between the volume collected at the technology point and the distance to

source. However, the mean daily consumption varies from 85 lpd in arid zones to 117 lpd in semi humid and highest in semi-arid areas at 179 lpd.

Theoretically, water demand ought to be dynamically related with water availability. Higher water availability should automatically elicit higher use (including new uses) creating a high demand. The reverse is also true: in areas where water is scarce, uses are more prioritised and demand focuses on primary needs first, which in general will lead to lower demand. Conspicuously, this is not exactly verified in the chart as shown in the Figure 17. One possible explanation is the subjective nature of the survey question as to what constitute “all uses”. It is likely that users in more water endowed humid and semi humid zones utilise improved water points for domestic uses and different sources for other purposes. This should however be confirmed by a more targeted study.







**Figure 17: Distance to source and daily consumption by ecological zones**

The study found that there is relationship between the demand responsiveness and sustainability of technology points and it is strongest where water caters for other needs besides water for domestic uses. Furthermore, the study found that gaps often exist between the perceptions of users and technology intermediaries<sup>20</sup>. These gaps pertain reliability of the technology based on co-opted project benefits, location of water point relative to users or either placing water point on their own property<sup>21</sup>, In other cases, it was found that community representatives failed to consider the demand of certain segments of the population, such as youth or the poor, leading to a design that did not reflect the preferences of the community as a whole. In such cases, community members often expressed dissatisfaction with the service provided, they possessed a low sense of ownership, and had little willingness to pay for the maintenance of the service<sup>22</sup>.

<b>Table 20: Number of Months Water is Available at Technology Points</b>			
		Frequency	Percent
Managers data	1 month	1	1.2
	2 month	1	1.2
	3-6 months	4	4.8
	6-9 months	3	3.6
	9-12 months	45	54.2
	Always	26	31.3
	None	3	3.6
	<b>Total</b>	<b>83</b>	<b>100</b>
Users data	1 month	2	1.5
	2 month	5	3.8
	3 month	3	2.3
	3-6 months	16	12.0
	6-9 months	28	21.1
	9-12 months	39	29.3
	Throughout	40	30.1
	<b>Total</b>	<b>133</b>	<b>100</b>

Generally, a reliable water source should provide water for a minimum of 350 days in a year, with less than 14 days of breakdown. Very few technology points were able to meet this standard. Users and technology point managers agreed that approximately 30% of the technology points provided water throughout the year, (Table 20). 85.5% of the technology point managers reported that water was in Embu were supplied with water for at least 9 months a year, compared to 92% in Baringo, 60 % in Isiolo and 57% in Homabay. Therefore, while Embu is better endowed with water resources, the county is more vulnerable to seasonal variation compared to the other three counties. Water supplies in the upper zones of Embu sourced water from surface stream flows which are more prone to volume variation between dry and wet season. This is in contrast to the semi-arid and arid areas which depend

<sup>20</sup> The term intermediaries is used to mean organization initiating, facilitating or undertaking implementation of water supply technologies on behalf of beneficiaries.

<sup>21</sup> In Runjenyes common water collection points (kiosks) have been disused for a longtime because users preferred individual connection on these water kiosk has since been demolish.

<sup>22</sup> 6 of 10 public water kiosks in Uriri, Migori that were developed around 2014 are non-functional because on unreliability and cost of water instead users obtain water from privately operated kiosks sourcing water from shallow wells.

on ground water sources that are nearly constant across different annual seasons. An additional dimension to this rests on the fact that Embu County has the highest demand for irrigation (71.4% of users). Irrigation is a dry weather activity and its impacts of water shortage are quite pronounced.

71 % of all the users interviewed used ground water supplies (boreholes and shallow wells) during the dry season. In comparison 74% of users utilised the same source in the wet season. 26% of the users reported utilising solar energy to abstract water from boreholes. The common complaint in all the counties is that solar technology performs poorly in cloudy weather and that the duration is limited when conditions are right for its functioning (8-9 hours daily). This nature of complain was especially articulated in Embu.

**Table 21: Common water sources during dry and wet seasons**

Water Source	Dry Season Source of water	Wet season source of water
Boreholes	67.0%	69.1%
water pans	16.0%	4.4%
River	10.6%	16.2%
Shallow well	4.3%	4.4%
Piped network	2.1%	5.9%
	100.0%	100.0%

#### Box 1: Design and Managment of Water Pans



Ol Donyiro pans in Isiolo were implemented by Caritas in 2015. There are two pans adjacent to each other. One of the pans has not been able to store water due to poor siting and one of its walls is breached. This water pan has a capacity of 50m x 50m by 4m, while the embankments on three sides go up 6m high. The volume of water in this water pan is limited by wall height on the inlet side. The water pan was dry during the time of study although it is reported to store water during the wet season.

The second pan measures 65m x 50m by 9m slanting but the water storage covers 48m x 33m. The Lower edge of the pan has breached causing loss of storage volume. Protection to embankment is well done but silt traps not installed.

Poor designs of water pans continue to impact on their storage ability. High cases of siltation on most of the dams were observed during the field study. Most of the water pans have not been de-silted for the last ten years. As compared to boreholes, most of the water pans lacked proper management structures and more than often maintenance issues are overlooked. Communities lack clarity on who is responsible for the system maintenance.

The overall proportion of users obtaining water from water pans increased from 4.4% in the wet season to 16%. Seemingly, the number of borehole users remain constant around the year, while water pans are the dry season alternative for users who mostly depended on surface stream abstraction in the wet season. In this sense, boreholes give the impression of meeting users demand in different seasons of the year while water pans, possibly because of

low water quality, are the users' safeguard in period of water scarcity or for lack of a better choice. Considering that 27% of users currently employ solar energy to abstract borehole water, there is potential to deploy solar PV to enhance water supplies to the remaining 44% of users who are using groundwater.

All users complained that quality of water obtained from water pans was poor. Moreover, observed water pans dried up during the dry season except two in Baringo, which have water available throughout the year. The water pans in Baringo were superior in many ways to those found in the other counties. These water pans included protection features, they had a well maintained fence to protect from stray animal and direct abstraction, gravel filtration, and silt traps. This evidence demonstrates that the challenges experienced with water pans (*see 6.3 for details*) has more to do with poor planning and construction other than an inherent nature of the technology.

### 6.2.1. Technology Capacity and demand coverage<sup>23</sup>

The total demand for water is analysed against information on different water uses, which includes water for domestic use, water for institutional and small business use. For rural areas this also includes water for livestock, water for crop agriculture, in particular through small-scale irrigation and water for seasonal population with their livestock. Demand coverage is then defined as the ratio of water supplied compared to total demand. The overall average household size in all the four counties is 7.1 with small variation between the counties, the highest being 8.5 in Homabay followed by 7.15 in Isiolo, 6.6 in Baringo and 6.2 in Embu.

**Table 22: Estimated Household Domestic water demand**

County	Average HH size	Average. Lower limit	Average. Upper limit
Baringo	6.58	66	132
Embu	6.26	63	125
Isiolo	7.15	72	143
Homabay	8.48	85	170
	7.12	71	142

According to Kenya's water supply design manual, (GOK (ministry of Water and Irrigation), 2005), daily per capita demand for rural household is between 10-20 litres for people without connection to water source and 40-60 for those with an individual connection. 2.1% and 5.9% of the surveyed users indicated to use individual connection during dry and wet season respectively. Therefore, the overwhelming majority fall under 10-20 litres daily category. The estimated demand Table shows a majority of the users' are expected to range between 60 and 140 lpd. Comparing with consumption data Figure 16, it's noted that 50% of the users fall within these margins with 16% and 34% on the lower and higher extremes respectively. Figure 18 is a line graph that compares the volume of water collected by users and what they required for their domestic uses. There is a direct correlation between water collected

<sup>23</sup> Water demand coverage refers to the ratio of available water resources relative to demand for given use(s)

daily and water needed for everyday use at 0.01 level of significance or degree of error. This therefore implies that users collected water in relation to the intended use for the water collected.

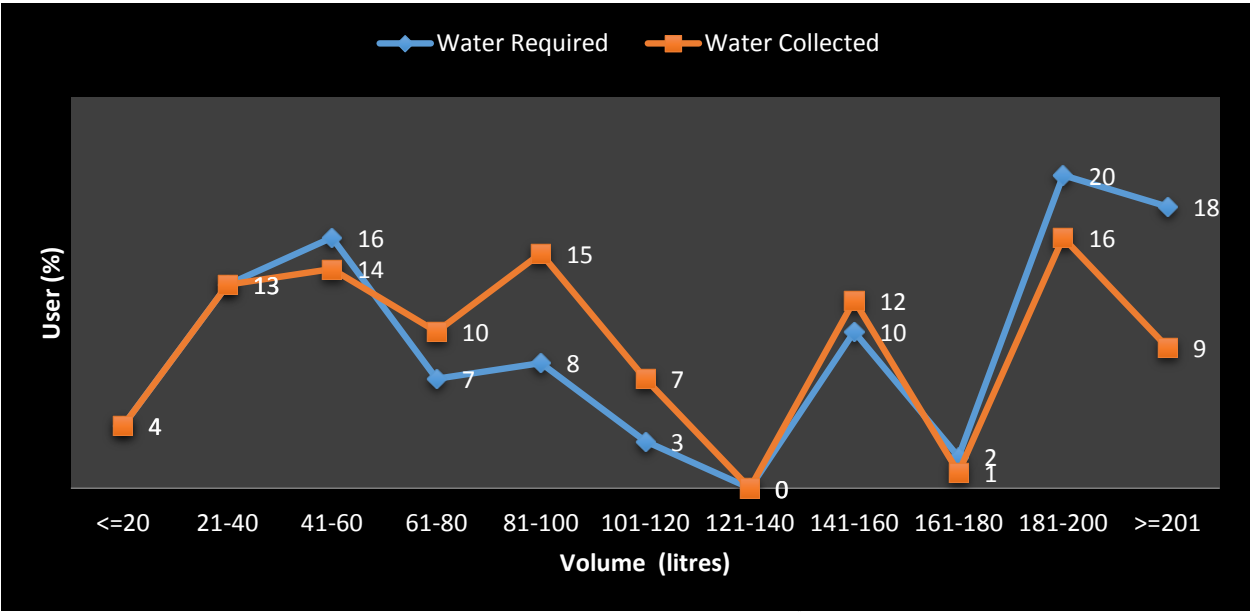


Figure 18: Comparison the water collected and required by users

It would be expected that easier, more efficient methods of abstraction raises the amount of water consumed. Figure 19 show the compares the amount of water that users collected from different technology points. Clearly there is no evidence that water consumption patterns varies depending on the technology in use. Meaning per capita consumption is unlikely to change with technology deployed. This has implication for the PPP financial analysis.

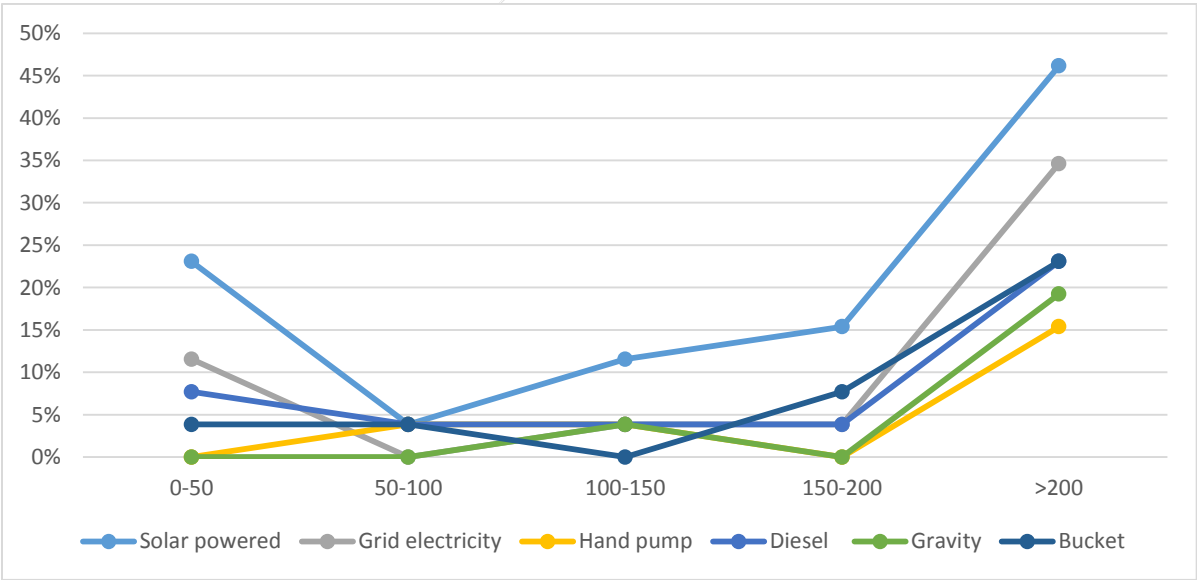


Figure 19: Water collected versus technology in use

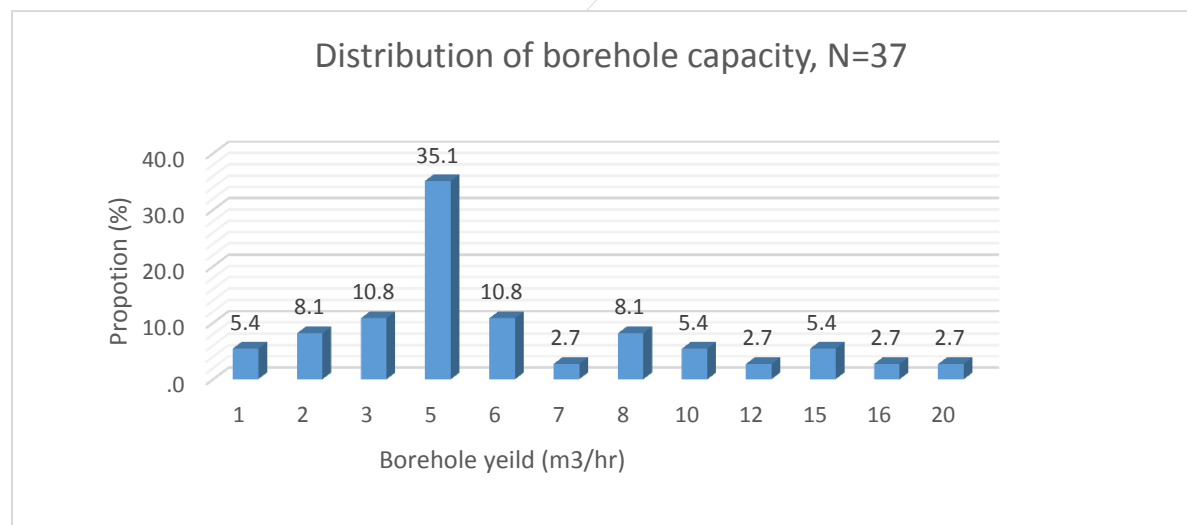
### a) Boreholes and water pans

On average the surveyed borehole supplied water to 141 households (HH) and 3350 livestock while the surveyed water pans provided water to an average of 162 HHs and 4357 livestock. Table 23 tabulates water demand per technology point based on current and improved future consumption. Each technology should have current capacity to supply approximately 65m<sup>3</sup> of water per day and 80 m<sup>3</sup> current and future demand without irrigation respectively.

**Table 23: Current and future multipurpose water demand**

	Borehole			Water Pan		
	Pop Served	Daily Current Consumption (m3)	Daily Improved Future supplies (m3)	Pop Served	Daily Current Consumption (m3)	Daily Improved Future supplies (m3)
Households <sup>24</sup>	141	15.0	30033	162	17.3	34.5
Cattle <sup>25</sup>	1887.19	31.5	31.5	1887.19	31.5	31.5
sheep & Goat	4760.76	15.9	15.9	4760.76	15.9	15.9
Donkey	96	1.0	1.0	96	0.7	0.7
Camel	70	1.8	1.8	70	1.8	1.8
Total Without Irrigation		65.0	80.1		67.0	84.3
Irrigation <sup>26</sup>	Current = 8.5 acres Future = 35 acres	106.8	443.1	Current = 9.7 acres Future = 40 acres	121.9	509
<b>Total</b>		<b>171.9</b>	<b>523.1</b>		<b>188.9</b>	<b>593.3</b>

Considering the safe borehole yield (Figure 20) and the 8-hours when condition are right for borehole operations, only 25% and 14% of the surveyed borehole had requisite yield of more than 7.5 m<sup>3</sup>/hr and 10.6 m<sup>3</sup>/hr respectively to meet current and future demand. This explains why 26% of solar system users



**Figure 20: Distribution of safe borehole yield**

<sup>24</sup> Current 15 lpd and improved 30 lpd calculated at an average 7.1 per HH

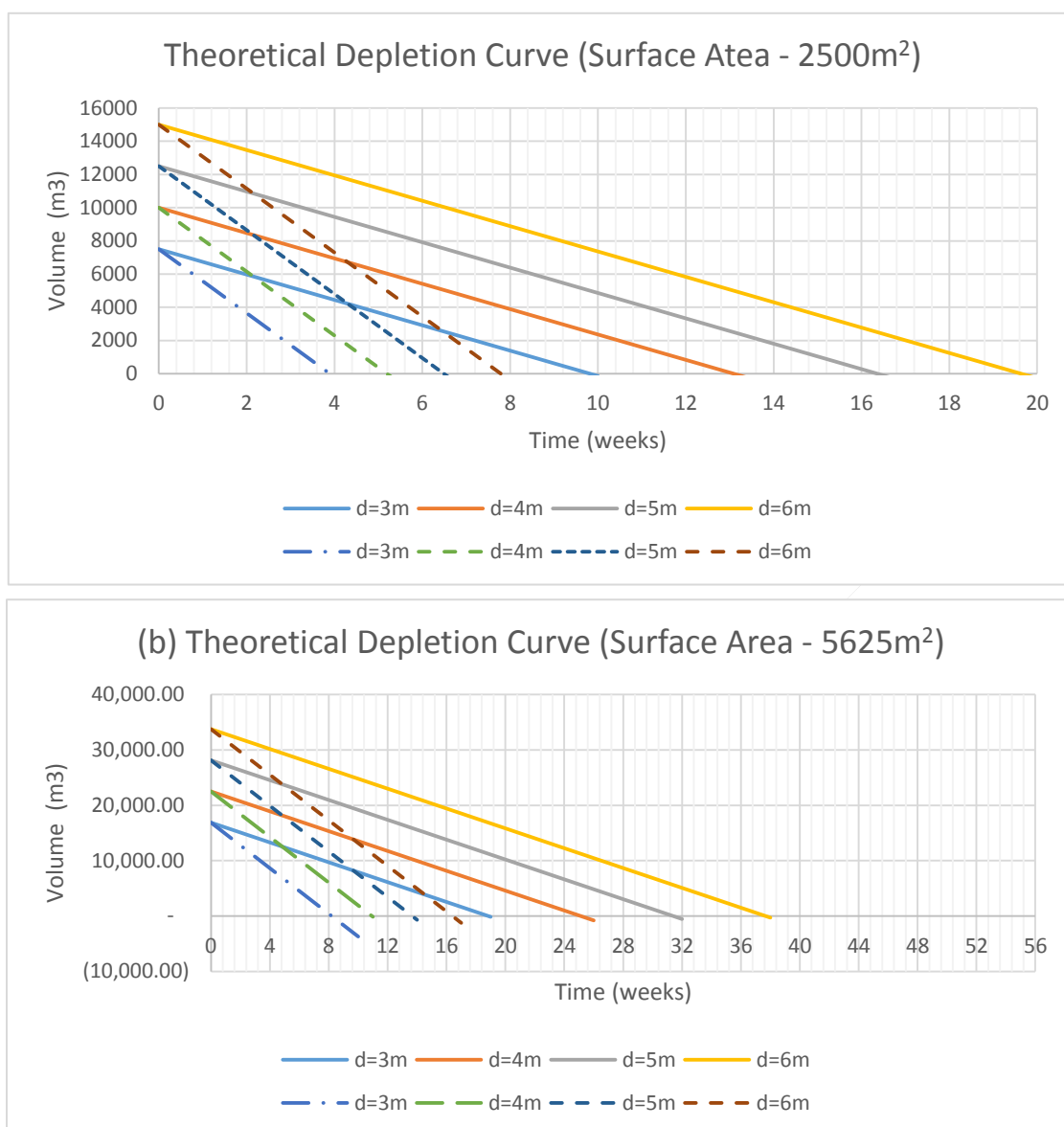
<sup>25</sup> 50 litres per livestock Unit (LU)

<sup>26</sup> 19% of the technology points incorporated small scale irrigation on average of 0.06 acres per HH. Size of irrigated future land is assumed at 0.25 acres per HH

reported the system to be unreliable. To guarantee reliability the option is to limit the number of households served by a particular water technology indicatively, 46% of Borehole have safe yield of 4-6 m<sup>3</sup>/hr or 32-48 m<sup>3</sup>/day. This is sufficient for domestic and livestock demand of 78 to 104 HHs. This is a good guide for planning but in practice, the size of community served will depend on the specific water uses in the community and water sources attributes.

The size of water pans and small dams ranged between 5,000 m<sup>3</sup> and 60,000 m<sup>3</sup> though 85% of the surveyed water pans were between 10,000m<sup>3</sup> and 30,000m<sup>3</sup>. In an ideal situation, this volume is sufficient to supply the 162 HH, (see Table 23). However, the annual potential open water evaporation is 2274 mm/annum in Marigat, Baringo and 2082 mm/annum in Mwea, Embu, (Woodhead, 1968). Typically, a water pan will lose 0.18 m<sup>3</sup>/m<sup>2</sup> per month through evaporation. This implies that 3m deep water pan will lose 5% of the stored volume every month by evaporation, while 4 m and 5m deep will lose 4% and 3% respectively. Soil Infiltration (movement of rainwater through unsaturated soils) and percolation (conductivity of water through saturated soils) are other important factors in the assessing the potential of water pan. Surface infiltration is an important factor to evaluate the retention capacity of storm or surface runoff from off season rainfall episodes. Percolation rate estimates water subsurface conductivity under steady moisture saturation. Infiltration rates of soils in Kenya range from 20-100 mm/hr, while subsurface conductivity will vary from slow (0.005 m/day) in clayey soils to moderately high (0.084m/day) in medium textured soils and very rapid 1 to 6m/day) in course textured soils ("Kenya Soil," n.d.).

This translates to daily infiltration loses in 7500m<sup>3</sup> unlined water pans at a rate of 0.19%, 0.14%, 0.11% and 0.09% of the stored volume in 3m, 4m, 5m and 6m water pans respectively under low percolation conditions or 420m<sup>3</sup> per month, and 2.4% 1.8%, 1.44% and 1.2% or 5400 m<sup>3</sup> for 3m, 4m, 5m and 6m deep pans in medium textured soils. Soil conductivity rates over 1m/day will result to losses in excess of 24m<sup>3</sup>/m<sup>2</sup>/day, which will drain water a pan of any size almost immediately. **Error! Reference source not found.** shows theoretical depletion curves combining households' consumption (65m<sup>3</sup>/day) evaporation and infiltration losses in low infiltration conditions (continuous lines) and high infiltration (broken lines). For a water pan with capacity of 7500 m<sup>3</sup> and a depth of 3-m in clayey soils will hold water for approximately 2 months but when the same water pan is located in medium textured soils, it will deplete in 1- month. On the other hand on an unlined water pan with a capacity of 30,000 m<sup>3</sup> and depth of 6m will be deplete in approximately 4 months when the site has medium textured soils but holds water for 8.5 months in heavy soil. It becomes clear that infiltration more than any other factors is critical in determining the services condition of the water pans. The size of the water pan and the surface to depth ratio are also very important. This situation correlates with field observations. Some pans were completely dry immediately after the rains while others had water for 2-3 months after the rains, especially in Isiolo. In other three counties water pans kept water for 4-6 months after the rains and few others especially in Baringo and Homabay retaining water for 9-12 months. It emerges that well designed water pans have excellent capacity to meet demand but water pans less than 30,000m<sup>3</sup> should be discouraged under any condition.

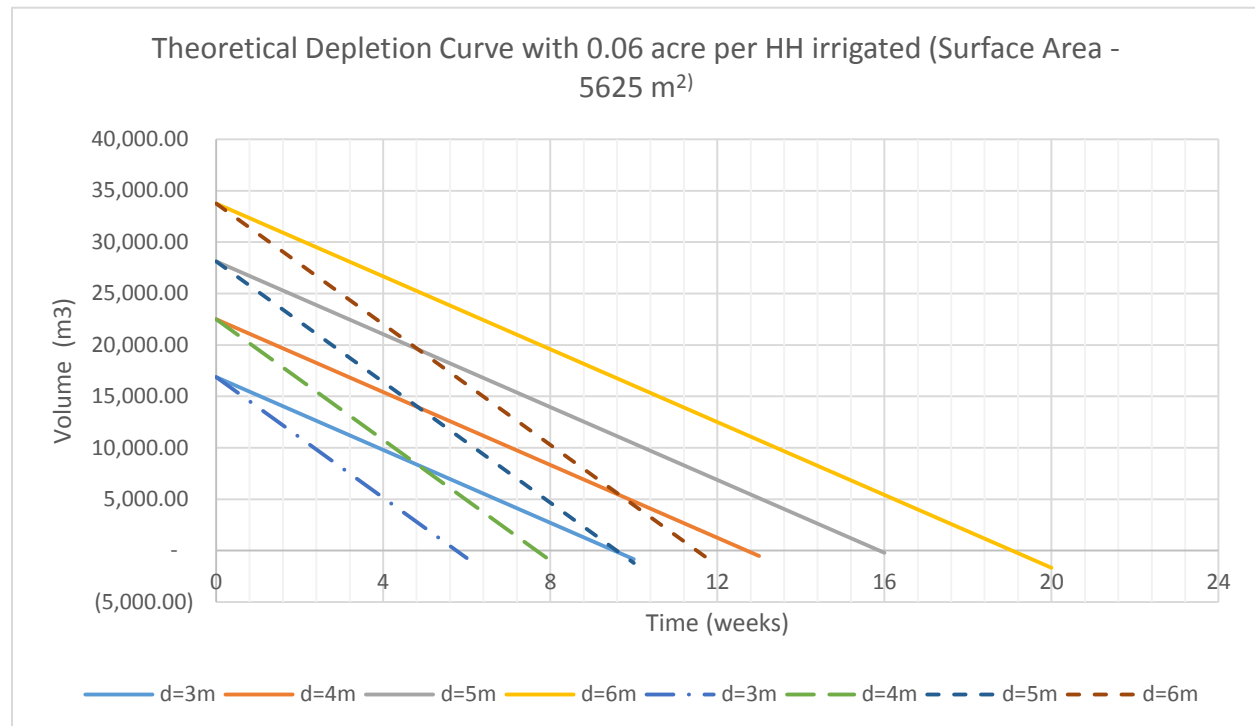


**Figure 21: Theoretical depletion curves without irrigation**

The current irrigation water demand is approximately 106.8 m<sup>3</sup>/day and 121.9 m<sup>3</sup>/day for boreholes and water pans respectively, based on 0.06 acre (approx. 15m x 15m) piece of land per household. The future irrigation water demand based on 0.25 acre of irrigated land per household is 443.1 m<sup>3</sup>/day for borehole and 509 m<sup>3</sup>/day for each water pan. Boreholes have limited capacity to support both current and future irrigation water demand. Moreover, 32% of the boreholes have salinity problems which render water unsuitable for irrigation. Another limitation to the use of borehole and solar PV technology for irrigation is the limited storage provided at the water point. In all solar technology points visited,



default 5m<sup>3</sup> plastic water storage tanks<sup>27</sup> were provided on elevated steel platform or on top of water kiosk. This size of storage is just enough to build localised head pressure for draw-off but not adequate for peak demand modulation.



**Figure 22: Water pan depletion under combined domestic, livestock and irrigation water demand**

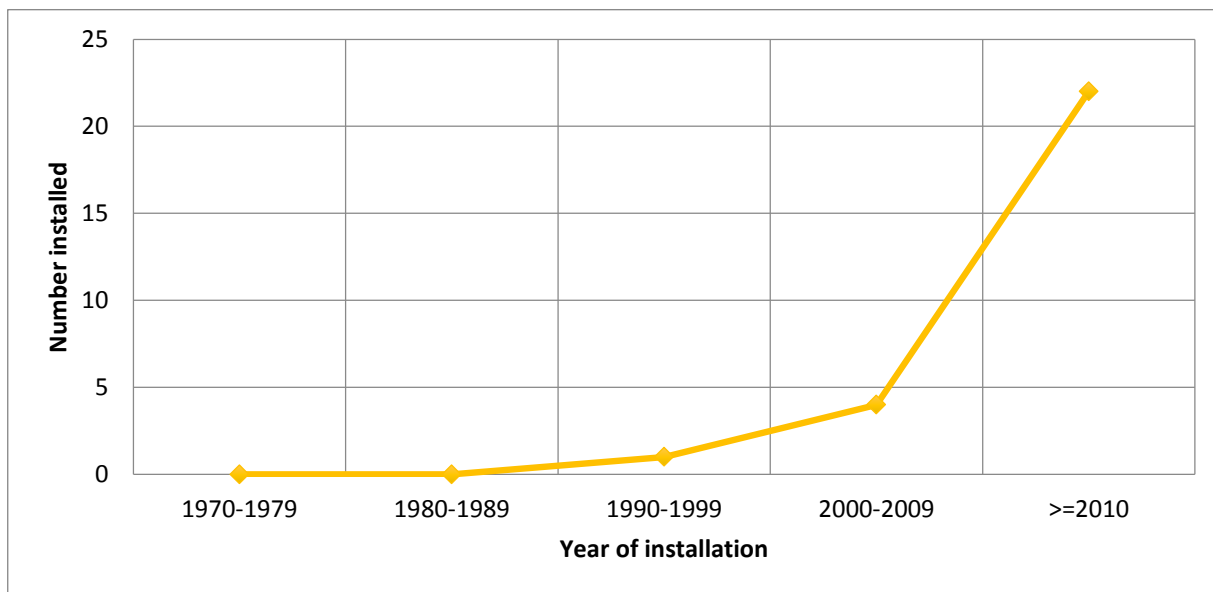
Figure 22 shows depletion scenarios for a water pan with a capacity of 15,000-30,000m<sup>3</sup> in Figure (b) when utilised to irrigate 15m x 15m farm. The duration of water availability range from 6 weeks for 15,000m<sup>3</sup> capacity pan in high percolation condition, to 22 weeks for 30,000m<sup>3</sup> in a pan of a depth of 6m. 22 weeks storage is sufficient to irrigate short growing crops (90-150 days). If the area under irrigation is increased to 0.25 acres, the duration of water availability is reduced to between 3-7 weeks, which may not be sufficient for most crops.

The duration of water availability is dependent on crop growth stages and the requirement of irrigation water application. The duration could also be extended by increasing the storage volume, if the catchment allows. Importantly, water pans show capacity to support irrigation demand alongside domestic and livestock uses, provided measures to control infiltration are incorporated in water pans designs. However water obtained from water pans has very poor quality for domestic uses.

<sup>27</sup> Leaching from plastic water storage tanks is a source of Polycyclic aromatic hydrocarbons (PAHs) pollutants which has been identified to increase the risk of reproductive difficulties and cancer (<https://www.epa.gov/ground-water-and-drinking-water/table-regulated-drinking-water-contaminants>)

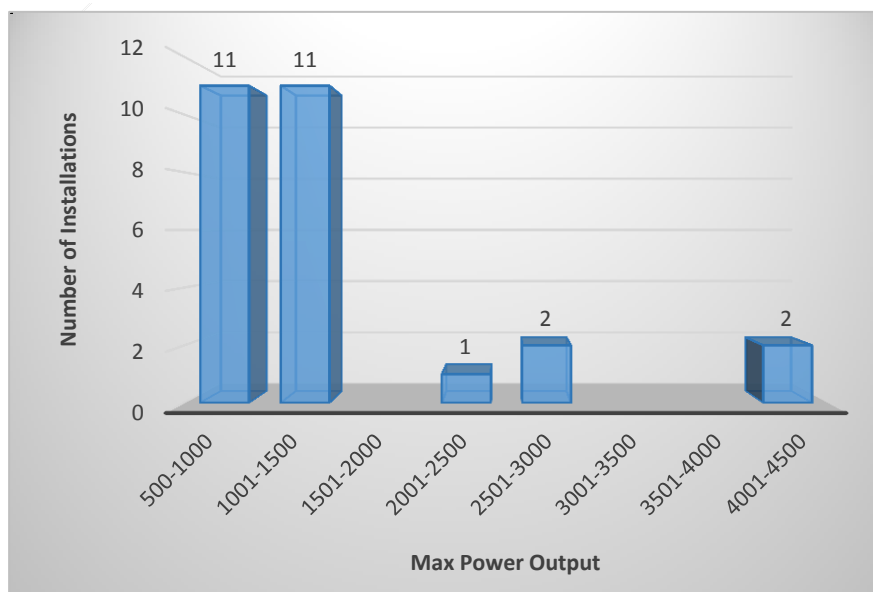
Lastly, it is evident that water pans stored water for limited period after the rains and therefore water pans are economical and reliable sources of water where dry weather is relatively short but less dependable in prolonged dry weather/drought conditions. The comparative advantages of the two technologies can be combined in a hybrid system of borehole surrounded by water-pans (for livestock and agricultural uses). In the events of drought the boreholes can still be used for livestock and domestic uses.

## b) Solar pumping technologies



**Figure 24: Growth of solar water pumping technology**

Out of the 27 solar powered technology points across the various ecological zones 61% are in arid and semi-arid ecological zones with 36% of this being observed in Isiolo County. 11% of the data collected on solar energy was collected in the humid to semi humid zones. The uptake of solar technology in the arid areas is considerably high as compared to the humid to sub-humid areas. From Figure 24, there is an indication that there has been an uptake of



**Figure 23: Distribution of installed solar PV by size**

the solar technology in the recent years with 81% of the visited solar pumping technology installed after the year 2010.

Figure 23 shows the distribution in size of the surveyed solar pumping technologies. The surveyed solar systems were small installation with 81% of the installations being of less than 1.5 kW. The smallest recommend solar pumping installation is 0.5 kW. Table 24 shows the common solar PV against the number of households that can be served by this capacity at different pumping head and at 70% efficiency. The pumping head is computed recalling that borehole depth varies from 60 to 200 m (section 6.1), and 10m pumping above ground. Generally, the small PV technology (<2kW) work for small community and ideally with small head lift requirement. For example Kanyathiang water in Homabay will require 11kW solar PV to meet the current (constrained) demand of 250m<sup>3</sup>/day and 87 kW to operate at full design capacity of 2000m<sup>3</sup>/day. Similarly, Garbatulla which had 5500 users or 750 HHs require solar technology with capacity for 25kW. Chepchamus water supply in Baringo County, the borehole yield is 4.9m<sup>3</sup> with static depth at 120m below ground. Water is delivered to an elevated tank that is 130m above ground which translates to 250m total head. This technology point requires a minimum of 5kW to provide the required water without factoring in lower energy output during cloud weather and probably the orientation of modules. With the current installation at Chepchamus borehole, the system may on average pump 0.8m<sup>3</sup>/hr or 16% of the capacity.

These challenges have led to a general perception that solar (and winds) are inferior technologies in comparison to the grid and generators. Gradually there is need to demonstrate that solar and wind are durable technologies suited for both small and large engineered applications. Development of a professional application of solar will increase with the capacity of the technology that is suited for high production boreholes. The high flow rate required for irrigation will necessitate even higher capacity of solar technology than commonly observed during the field survey. For instance 500m<sup>3</sup>/day at 20 m lift and 30 m operating head will require a 20 kW solar arrays.

**Table 24: Required Capacity of solar PV (kW)**

		Pumping head (m)										
HHs Served		70	80	90	100	110	120	130	150	175	200	250
15		0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.6	0.7	0.8
30		0.5	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.2	1.3	1.7
45		0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.8	2.0	2.5
60		0.9	1.1	1.2	1.3	1.5	1.6	1.7	2.0	2.4	2.7	3.4
75		1.2	1.3	1.5	1.7	1.8	2.0	2.2	2.5	2.9	3.4	4.2
90		1.4	1.6	1.8	2.0	2.2	2.4	2.6	3.0	3.5	4.0	5.0
105		1.6	1.9	2.1	2.4	2.6	2.8	3.1	3.5	4.1	4.7	5.9
120		1.9	2.1	2.4	2.7	3.0	3.2	3.5	4.0	4.7	5.4	6.7
135		2.1	2.4	2.7	3.0	3.3	3.6	3.9	4.5	5.3	6.0	7.6
150		2.4	2.7	3.0	3.4	3.7	4.0	4.4	5.0	5.9	6.7	8.4
165		2.6	3.0	3.3	3.7	4.1	4.4	4.8	5.5	6.5	7.4	9.2
180		2.8	3.2	3.6	4.0	4.4	4.8	5.2	6.0	7.1	8.1	10.1
195		3.1	3.5	3.9	4.4	4.8	5.2	5.7	6.5	7.6	8.7	10.9
210		3.3	3.8	4.2	4.7	5.2	5.6	6.1	7.1	8.2	9.4	11.8
225		3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.6	8.8	10.1	12.6
240		3.8	4.3	4.8	5.4	5.9	6.4	7.0	8.1	9.4	10.7	13.4
255		4.0	4.6	5.1	5.7	6.3	6.8	7.4	8.6	10.0	11.4	14.3
270		4.2	4.8	5.4	6.0	6.6	7.3	7.9	9.1	10.6	12.1	15.1
285		4.5	5.1	5.7	6.4	7.0	7.7	8.3	9.6	11.2	12.8	15.9
300		4.7	5.4	6.0	6.7	7.4	8.1	8.7	10.1	11.8	13.4	16.8
315		4.9	5.6	6.3	7.1	7.8	8.5	9.2	10.6	12.3	14.1	17.6
330		5.2	5.9	6.6	7.4	8.1	8.9	9.6	11.1	12.9	14.8	18.5
345		5.4	6.2	7.0	7.7	8.5	9.3	10.0	11.6	13.5	15.4	19.3
360		5.6	6.4	7.3	8.1	8.9	9.7	10.5	12.1	14.1	16.1	20.1
375		5.9	6.7	7.6	8.4	9.2	10.1	10.9	12.6	14.7	16.8	21.0
390		6.1	7.0	7.9	8.7	9.6	10.5	11.3	13.1	15.3	17.5	21.8
405		6.3	7.3	8.2	9.1	10.0	10.9	11.8	13.6	15.9	18.1	22.7
420		6.6	7.5	8.5	9.4	10.3	11.3	12.2	14.1	16.5	18.8	23.5
435		6.8	7.8	8.8	9.7	10.7	11.7	12.7	14.6	17.0	19.5	24.3
450		7.1	8.1	9.1	10.1	11.1	12.1	13.1	15.1	17.6	20.1	25.2
500		7.8	9.0	10.1	11.2	12.3	13.4	14.5	16.8	19.6	22.4	28.0
750		11.8	13.4	15.1	16.8	18.5	20.1	21.8	25.2	29.4	33.6	42.0
1000		15.7	17.9	20.1	22.4	24.6	26.9	29.1	33.6	39.2	44.8	56.0
1250		19.6	22.4	25.2	28.0	30.8	33.6	36.4	42.0	49.0	56.0	69.9
1500		23.5	26.9	30.2	33.6	36.9	40.3	43.6	50.4	58.8	67.2	83.9
4348		68.1	77.9	87.6	97.3	107.1	116.8	126.5	146.0	170.3	194.6	243.3

**c) Small Wind Turbines**

Four out of the five wind systems observed during the field study were not functional. It was difficult to follow up on data on these systems and therefore had a challenge in determining the capacity of these systems. Furthermore, the number of dealers and manufacturers visited did not provide adequate data to quantify the capacity of the systems. From secondary data obtained, small wind turbines are available in varying sizes ranging from 50W to 10 KW. The small wind turbines can be designed for 12V direct

current and 240V for alternating current. Proper siting is paramount in enhancing wind flows. Large structures are known to inhibit wind flows and therefore SWT are not suitable in a built environment.

### 6.2.2. Land availability for technology Installation

Production of solar energy and wind for large community water supply projects requires significant areas of land. This is equally important when developing green water storage infrastructure such as water pans, which require large size of land for retaining water especially during the dry season. The

#### Box 2: Mogotio Water Pan: Land availability for water infrastructure

Mogotio ward is within the semi-arid ecological zone faced by cases of water scarcity. Water scarcity in this areas resulted in;

- Lack of water for domestic use as well as water for their livestock therefore affecting their livelihoods
- Increased cases of water borne diseases
- Long distances in search of water for their domestic use and for their livestock
- Limited social economic activities

National Youth Service develop three water pan; one with a capacity of 60,000m<sup>3</sup> alongside two 30,000m<sup>3</sup> each. The water pan improved accessibility of water especially for livestock. Nonetheless, the pans have been developed in a private land and therefore limiting accessibility. The land owner has not been compensated for the land. The community reported that they were not involved in the initial stages of project design. These investments have huge capacity of water storage with a series of water pan within the same area but the impacts are not widely felt.

#### Lessons

- i. Community participation is very important towards ensuring demand and sustainability of project.
- ii. Land tenure is a serious issue that needs to be addressed and agreed upon before commencement of the project.



land requirement per each of the selected technology varies depending on size of technology, type of soils required and the designs. For larger solar and water pan application, land availability considerations is fundamental.

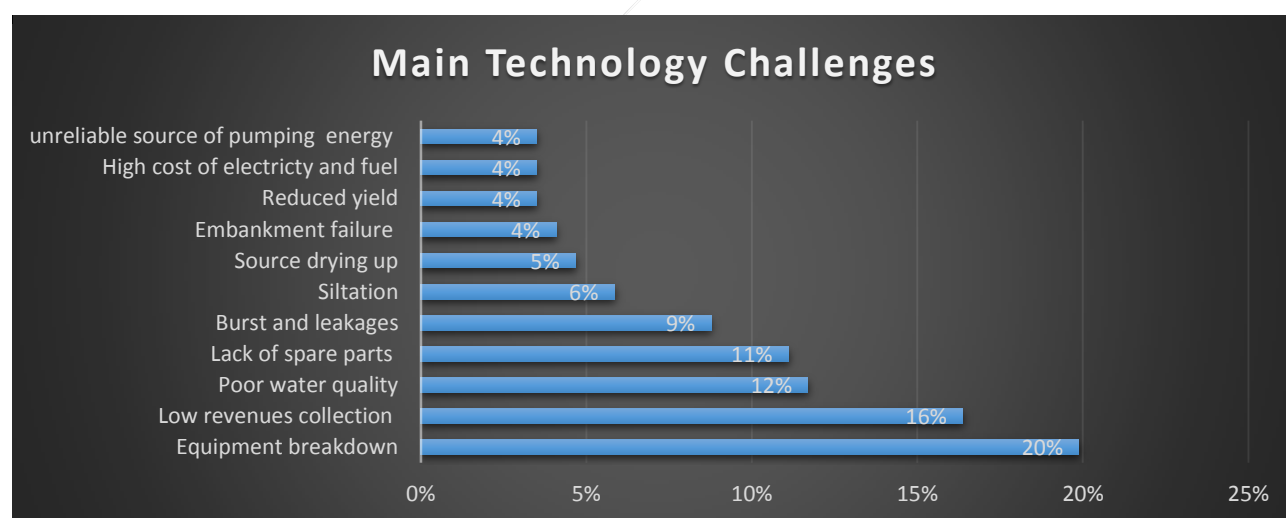
In small solar water pumping system, the modules are closely placed together and therefore the size of land for such arrangement is small. In Chepchamus the borehole was equipped with 26 solar modules, each module having an area size of 1.2m<sup>2</sup>, with a total of 32m<sup>2</sup> on elevated platform. For bigger community project, the land required for harvesting huge solar energy is bigger. Davis and Shirtliff company in Wajir county has a total power of 24KW, with a borehole yield of 14m<sup>3</sup>/hr at a total head of 227m. This array

requires 192 modules and 15m x 15m piece of land. Limited availability of this size of land has potential to restrict application of the selected technologies in peri-urban and densely populated rural areas. Appropriate mechanisms or partnerships are needed to ensure availability of land at the lowest possible cost. 56.2% of the surveyed technology stands on community land, 16.9% on public land and 14.6% on privately owned land.

### 6.3. Durability and Serviceability

Durability is important in understanding the potential of the selected low cost green technologies to meet water demand over a long period of time under normal condition of use, expenditure and maintenance. Experience in Kenya is that many newly built infrastructures deteriorate after the project's termination. Less than 15% of technologies more than 10 years since installation was found to be operational. Therefore, it is imperative to plan for effective operation and maintenance as it is an essential precondition to successful deployment of low cost technologies for water supplies.

While water coverage in rural areas is reported to have improved from 40% in 2007 reaching 48% in 2015,(Water Services Regulatory Board (WSRB), 2016) many of these infrastructures are no longer functioning as initially designed. Although operation and maintenance (O&M) activities are often used as one term, it is important to distinguish between the two. Operation denotes the direct access to the system by the users – the regulations that govern who may access the system, when, and under what conditions, and routine procedures supporting access. By contrast, maintenance<sup>28</sup> is about the technical activities which are needed to keep the system working and durable including skills, tools and spare parts.



**Figure 25: Main technology Challenges**

<sup>28</sup> Preventive maintenance is planned and carried out on a regular basis to maintain the infrastructure in wholesome condition and includes minor repairs at scheduled assessment, cleaning and greasing of mechanical parts and replacement of parts with a limited lifespan. Corrective maintenance has to do with replacement or repair faulty component, while reactive maintenance is a consequence to a crisis or complaints. It's maintenance at failure, malfunctioning or breakdown of equipment.

In all, 53% of technology challenges enumerated by managers relate to post-construction maintenance (equipment breakdown, lack of spare parts, burst and leakages, siltation, embankment failure, unreliable source of pumping energy) Breakdown of equipment and lack of spare parts was mentioned as the key challenge affecting technology accounting for 31%. Operational issues (low revenues collection, high cost of electricity and fuel) comprised 20% of challenges by managers, of which collection of revenues to meet O&M accounted for 16%, while quality and reliability of water sources (poor water quality, source drying up and reduced water yield) represented 20% of challenges identified.

In 62% of the technology points, maintenance take place once a year or at random irrespective of the technology type in use. Prominently, all the 6 technology points in humid and sub-humid zones are maintained daily, monthly or quarterly. In 31% of the cases it took two months or more to repair technology break down. On average, it took 33 days before the repairs are undertaken. This finding supports the perception that even when communities embrace ownership they may lack the capacity to operate and maintain the system on their own. However, instances where technology addressed multiple uses of water, the users largely identified with the technology and their willingness to maintain the system sustainably was high. This was evidenced in Embu County.

Drawings lesson from hand pumps, the technology has been promoted as a sturdy technology, suited for village level operation and maintenance. The access to the wearing parts was considered relatively unproblematic. These characteristics made hand pump an inexpensive and attractive option for rural water supply. The evidence coming out of the study points is contrary to this view; 58% of the hand pumps visited was nonfunctional and many others were reported to have been abandoned and later replaced with solar installation. The faulty components are often small and inexpensive parts. The experience is very similar for mechanical wind pumps where the largest cause of malfunctioning was broken rubber seal inside the casing wall. The technology provider, Bob Harries Engineering Limited, had only one service center in Thika, 40 km north east of Nairobi. Users interviewed reported difficult in sourcing maintenance support or spare parts in the urban centers nearest to them or otherwise difficulties in contacting the technology supplier. In several cases they turned to the implementer for assistance, but many eventually abandoned the use of technology when no assistance was provided. Surprisingly, all of diesel generators observed during the survey were in functional state compared to 85% of the solar installations. 15% non-functional rate of solar installations is significantly high considering that the majority of the installations are hardly 5-years old. A possible explanation is that diesel generators are well known technologies among communities. The technology and spare parts market chain is well established and in addition local skills for repair are available.

Rural Focus a local NGO with support of DFID and several partners implementing field trials of Smart Hand pumps project in rural Kenya in 2012-13 found that most abstraction methods fitted on community owned boreholes/ shallow wells cease to function after the second year. The project fitted hand pumps with an accelerometer calibrated to send a signal on usage and non -usage as well as the quantity of water being extracted. Mobile networks allow for improved management of multiple hand pumps, thereby reducing operational and financial costs. The system allowed the immediate detection

of hand pump failure and ensured quick repairs are made quickly. It further improved accountability by providing monthly statements of revenue and expenditure to communities. The scale of the project made use of trained technicians to do the repairs using high quality spare parts available within the community.

Davis and Shirtliff and Grundfos had deployed an IT supported system that allowed diagnosis of operational faults from the head office and service centres. This ensured timely and pointed response. The users of Grundfos operated solar technology in Embu reported that repairs were undertaken within hours of report being made. Therefore maintenance comprises not only technical skills, but also managerial, financial and institutional outreach.

In summary the following is observed in relation to maintenance and durability of technology deployed for water supplies;

- i. Technology intermediaries concentrated on development, and post-construction follow up is minimal or non-existent;
- ii. Neglect or delay in applying proper maintenance adversely affect the credibility of the technology, its further development of future projects, as well as the well-being of served populations
- iii. The management capacity of local water committees, despite initial training, drops dramatically over time as trained people lose interest, lack access to skills upgrading, or simply move away;
- iv. Community may have succeeded ensuring operation of the technology but maintenance is limited.
- v. As rural water supply systems become more technologically complex or as the number of users increases, technology and customer-management becomes an increasing challenge
- vi. Spare parts for routine maintenance, trained mechanics and equipment for handling major repairs may be difficult to find, which result in the infrastructure being non-operational for long periods of time.
- vii. some private sector models have been developed which have showed good potential to cover maintenance in poorer, dispersed communities

#### **6.4. Technical skills for up scaling**

Big strides have been achieved in the management of urban water supply sources, many of which are maintained by formal water service providers operating under a performance licence from one of the seven (7) water services boards. Similar progress has not been observed with water supply sources in rural areas. Private or commercial arrangements are less prominent in the management of dispersed rural water technology points. Other than for social consideration, self-supply has been embraced as low-cost way to co-finance and expand water supplies. The absence of formal institution presents challenges with respect to how best to harness the skills needed for deployment and sustaining low cost green technologies for water supplies technology. Privately operated water kiosks have increased over the last decade though the concept is young and developing, serving a small segment of the rural water



market. Few formal initiatives have been scaled up beyond the pilot stage and few individual technicians and artisans are active in supporting the selected technologies. All these approaches increase rather than replace community based management which results in inconsistencies in operation and maintenance of the selected technologies.

At the national level, Water Services Trust Fund is actively focused on providing limited financing needs for rural and peri-urban areas but it is not engaged in follow up actions especially on the technology operation and maintenance. While devolution of water services has been reinforced by the 2010 constitution of Kenya, gaps exist at the county and sub-county level with project intermediaries focusing more on development of these technologies and less on maintenance. In most cases the water committee manages and oversees the system's operation, which includes conducting preventive maintenance, collecting tariffs or payments for repairs, keeping records of financial transactions, manuals and blueprints, sanctioning people for non-payment, and ensuring that repairs are made.

Caretakers responsible for technology points are typically local people with basic or no formal training for the job. 75.3% of all the care takers interviewed have learned their duties 'on the job', while 9% have only certificate training. 58% of the caretakers have never received any training specific to the installed technology. 12% of caretakers have received short training on the operation of the system from government and 9% from the technology suppliers. This reflects a serious neglect of this crucial component of technology management by the key players.

**Table 25: Level of training**

<b>Training Provider to caretakers</b>	<b>Percent</b>
Government	12%
Water Service Providers	4%
Technology suppliers	9%
NGOs	3%
None	58%
Others	14%
<b>Total</b>	<b>100%</b>

Without external assistance, the opportunities to harness market forces to up-scale technologies and expand coverage in rural areas appear to be restricted. Contract-based operator arrangements have been introduced as possible alternatives for water point management by among others SNV and Kenya Market Trust. A few Contract-based operator arrangements have been tested in the western Kenya and the result have shown great potential in improving efficiency and sustainability of water supply systems.

Drawing lessons from Davis & Shirtliff, Rural Focus and Grundfos in deployment of rural water technologies, for improved efficiency and sustainability rural water supply should not only adopt curative approach that only address technology repairs but also preventive approaches that regularly diagnoses water systems. Preventive approach ensures water managers are advised before an equipment breakdown. Service contracts should cover equipment repairs and maintenance issues

where technology supplier commits to visit the technology two or three times a year to make a diagnosis and prevent breakdowns.

Construction quality has major impact on sustainability. Qualitative assessments especially for water pans exposed that poor design and construction quality lowered the chances that the system would be sustained. In Isiolo, several cases of dry water pans were encountered where the water pan could not collect any water due to poor sitting, poor soil conditions and embankment failure because safe overflow paths had not been provided. This shows that exhaustive investigation had not been done or the designer lacked competence to undertake the work. This problem affected systems built by private contractors, by community members and by state agencies.

The findings show that low cost technologies in rural areas do not receive the same attention in term of availability of spare parts and O&M skills as compared to the development of conventional infrastructure. Poor construction quality was more likely to occur when supervision was limited due to distance from the offices of intermediaries and difficulty in site access. World Vision (Kenya) narrated several instances where weak professional inputs such as hydrogeological survey, hydrological analysis, inappropriate sizing of components and water pan protection were the main cause of technology failure. Consequently, World Vision has established internal technical planning unit properly equipped with the necessary field survey equipment and maintenance skills.

Generally, there are few professionals knowledgeable in engineering of rural water technologies and/or the financial budget may not be sufficient to support for a detailed site investigation. Provision of capacity to professional staff involved in community systems is closely linked to the quality of construction. The capacity may include some kind of certification training, access to planning data and if necessary collective access to equipment and tools otherwise are not readily available.

## **6.5. Summary**

- i. The spread of the selected technologies across the four counties is evident with solar being the predominant water abstraction method especially in semiarid to arid areas. The observed water supply systems were small scale intended to serve few number of household and therefore had low impacts. The water pans observed were between 10,000 m<sup>3</sup> and 30,000 m<sup>3</sup> and therefore they retained water 4 to 6 months in a year.
- ii. Water pans are primarily developed to support water for farming and livestock use with minimal use for domestic uses due to poor quality of water. Water pans stored water for limited periods after the rains and therefore water pans are economical and reliable water storage structure in regular water conditions, fairly better in zones with short dry weather but less dependable in prolonged dry weather conditions. Well-designed water pans have excellent capacity to meet demand and to maximise benefits and therefore bigger investments for water pan above 30,000 m<sup>3</sup> should be developed.
- iii. There has been steady uptake of solar water pumping systems from the year 2000 onwards.
- iv. The use of water pans as small storage structures have been adopted alongside other structures such as earth dams, sand dams and small dams all distributed across all ecological zones.

- v. Water uses varies across different counties and ecological zones. Water for domestic use is dominant in all counties with most being supported by varied water abstraction methods namely; solar, diesel generators, gravity and grid electricity.
- vi. Boreholes observed had limited capacity to support irrigation. The limited storage (mostly 5-10 m<sup>3</sup>) provided at the water point further limits the use of borehole and solar PV for irrigation.
- vii. The use of unskilled people in managing the O&M component continues to impact on functionality rate and sustainability of the low cost supply systems. Government, donors and NGOs have widely been involved in providing capital cost for the development of water investments with little consideration to supporting the O&M component. The communities lack the capacity to perform their day to day maintenance of the water supply. There is need to develop a strong post implementation at the community level and a need for the implementers to operationalize and monitor operation and maintenance of water supply structures.

## 7. Economic Analysis of Low Cost Green Water Technologies

*The analysis presented in this section considers the cost effectiveness of the selected technologies against the benefits. The analysis is oriented to support decision on the most efficient means of deploying the selected technologies.*

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The economic analysis of low cost green technologies seek to determine the value of these technologies to the community on and where possible compared to options such as electricity, hand pumping, diesel or no-technology options. The economic analysis assesses the capital and operational costs, cost effectiveness and cost recovery of the selected technologies. The analysis compares the relative costs to outcome of these technologies in enhancing sustainable water supply.

### **7.1. Capital Expenditure and Affordability**

The actual capital, operation and maintenance expenditures of surveyed technology sites were rarely reported accurately and documentation related to cost was rarely available. This was especially the case with respect to capital expenditure as well as operation and maintenance cost. This lack of clarity often means that it is challenging to determine precisely the intended outputs, what was actually delivered or how much it cost.

Table 26 shows the construction cost of abstraction technologies reported by the managers of surveyed points. It is important to draw attention to the fact that the reported costs do not always cover the entire value of the water supply system. For instance, the capital cost of a borehole in Homabay was reported as Ksh 1.3 million, which compared to the market rates in Kenya, may not be realistic. It is likely that this cost relates to the latest technology upgrade in the installation of a solar pumping system. In other cases, the cost reported goes beyond the specific technology as the example of Nalepo women group in Baringo shows. Here, the cost reported includes borehole drilling, solar installation and pipe network to distribute water from borehole source. Table 26 shows that 53% of the observed investments cost less than Kshs 1 million, while 87% of all capital investment was less than Kshs 10 million. The field survey findings shows that the average cost of developing a borehole equipped with solar pumping is Kshs 3.45 Million, Kshs 1.86 million for borehole equipped with diesel engine and Kshs 10.5 million for systems that are powered by grid electricity. The latter most likely includes the cost of distribution network. Table 27 is a typical commercial quote for drilling and equipping 200-m with 5kW solar pumping near Nairobi. It validates the reported cost of solar water pumping system. The higher cost reported during the survey may be as result of transport cost and other logistics associated with implementation in the ASALs.

**Table 26: Distribution Capital Cost Per Technology**

Capital Costs	Solar powered	Wind powered	Grid electricity	Gravity	Bucket	Total	Total (%)
<=1000000	18	2	7	2	4	46	53%
1000001-10000000	9	3	7	1	7	30	34%
10000001-20000000	1			1		3	3%
20000001-30000000			1			1	1%
40000001-50000000				1		1	1%
>=50000001			4	2		6	7%
<b>Total</b>	<b>28</b>	<b>5</b>	<b>19</b>	<b>7</b>	<b>11</b>	<b>87</b>	<b>100%</b>

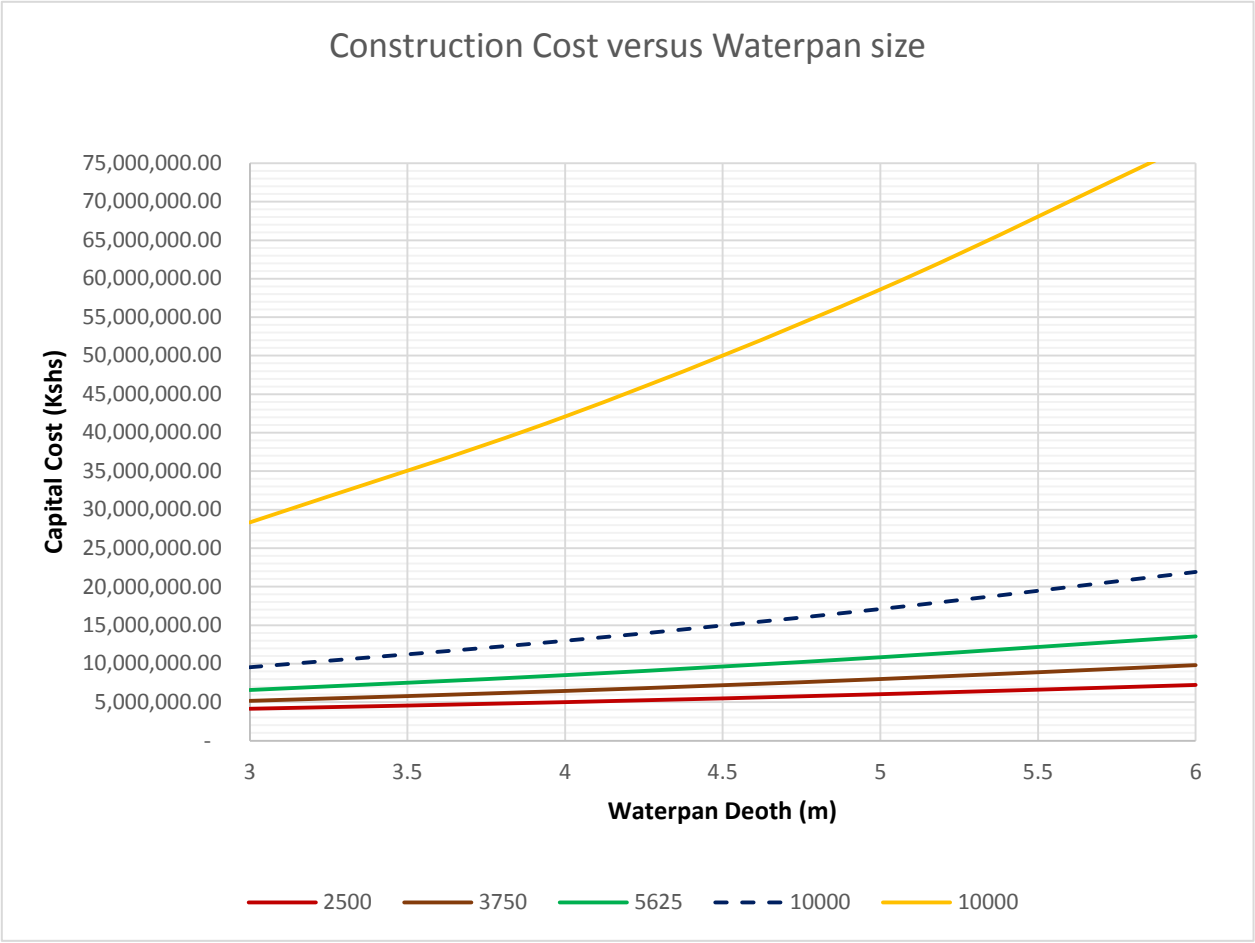
**Table 27: Typical commercial quote for 200mm deep borehole fitted with 5kW solar pumping**

Description	QTY	RATE	TOTAL (Ksh )
Drilling Borehole 200m	200	700	140,000
Storage Tank			650,000
Pump C/W 5kw Motor	1	300,000	300,000
6mm <sup>2</sup> 4-Core Flat Submersible Cable	180	480	86,400
Charge Controller	1	450,000	450,000
260w Crystalline Solar Modules	20	23,500	470,000
Pv Disconnect Switch 1000v-40a	1	55,000	55,000
Lockable Controller Box	1	8,000	8,000
Electrode Cable	260	20	5,200
Lorentz Well Probe Sensor	1	6,000	6,000
Galvanized Iron Pipes Class B 11/2"	30	3,200	96,000
Crane Sockets 11/2"	31	640	19,840
11/2"X6" Borehole Cover C/W Sundries	1	27,000	27,000
6mm <sup>2</sup> 4-Core Underground Cable	25	500	12,500
1.5mm <sup>2</sup> 2-Core Underground Cable - Electrodes	25	120	3,000
6mm2 Twin Flat Cable	40	230	9,200
Earth Rod C/W Clamp	1	1,000	1,000
6mm2 Earth Cable	10	230	2,300
Cooling Sleeve	1	9,000	9,000
Water Meter 11/2"	1	34,000	34,000
Solar Module Support Structure	1	195,000	195,000
25mm Pvc Airline Pipes	30	220	6,600
Installation Sundries	1	10,000	10,000
Installation, Labour And Transport	1	120,000	120,000
<b>SUB TOTAL</b>			<b>2,716,040</b>
<b>ADD 16%VAT</b>			<b>277,606</b>
<b>TOTAL</b>			<b>2,993,646</b>

The average cost rate of constructing water pans is Kshs 302/m<sup>3</sup> of water stored though the rate is not consistent and varies widely from Kshs 88 to 1200/m<sup>3</sup>. The average size of a water pan is 17,800m<sup>3</sup> costing Kshs 5.4 million. Figure 26 shows the cost curves of water pan construction based on rough construction costs estimates in Kenya. The unit rates ranges from Kshs 318 to 553 per m<sup>3</sup> depending on

the depth, volume and economy associated with size and include the cost of excavation, protection, equipping with solar pump and professional inputs. This means that 10000 m<sup>3</sup> water pan costs about Kshs 5.0 million, 30,000m<sup>3</sup> costs Kshs 9.5 million, 70,000m<sup>3</sup> costs Kshs 22 million, while 100,000m<sup>3</sup> pan will cost approximately Kshs 59 million.

The financial budget tabulated in Table 26 was 53% of the cases be sufficient to cover the cost of a borehole with solar pumping or a water pan bigger than 10,000m<sup>3</sup>. This probably explains why the majority of water pans observed are between 10,000-30,000m<sup>3</sup>. It seems that the emphasis is on supplying as many people as possible with improved water within the available budget, leading to cost ceiling. This approach tends to emphasize on the number of water pans rather than on optimizing cost effectiveness. With all its worthy intentions, the risk of this approach is that it ends up being counterproductive if the drive to reduce costs and increase the number of technology points is at the



**Figure 26: Construction Cost versus size of water pan**

expense of quality, where cheaper product are prone to early failure.

For instance, a water pan with capacity of 10,000m<sup>3</sup> will cost Ksh 5 million, and as illustrated in Figure 26 it will at best supply water for 13 weeks and in poor unlined soils for only 5 weeks. On the other

hand, 30,000 m<sup>3</sup> water pan whose capital cost is estimated at Ksh 9.5 million will supply water for 32 weeks with good underlying soil conditions or bed lining otherwise for about 14 weeks. The risk associated with limited capital budget is that choice is often made to go with smaller size or important components for example infiltration or silt control are omitted. As stated earlier on average cost of a borehole fitted with solar is approximately Ksh 3.45 million, and if faced with limited budget components such as size of water storage, optimum depth of borehole, and quality of solar installation might be compromised or abandoned for an alternative with lower initial cost. Whichever the case, the usefulness of the technology is compromised if the available budget is constrained or shared thinly between points for the purpose of meeting short-term outputs - to increase coverage defined as number of technology in a given area - as opposed to focusing on the outcome – adequate water to meet water demand.

In most cases the capital cost has been provided by donor and government. 48% and 46% of the technologies have been financed directly by donor/NGOs and government, with an average contribution at 80.5% and 76% of the capital cost respectively. The beneficiaries contributed to capital finances in 17.5% of the surveyed technologies points at an average of 19.5% of the total cost of the water supply system. Based on the on the trends that communities contribute 20% of the initial cost, each household would be required to contribute an average of Ksh 11,800 and Ksh 4,300<sup>29</sup> for development of 30,000m<sup>3</sup> water pan and borehole fitted with solar pumping respectively. Considering significant number of Kenya's rural population earns less than Ksh 200 per day, this represent at least 2 month worth of income in co-contribution (in cash or in kind). Larger investments which are better suited for multiple water use, would require the beneficiaries to contribute an even higher amount. This is increasingly more expensive for the beneficiaries to afford. Where this criteria is applied strictly, and the beneficiaries can't meet the requisite co-contribution the options is to downsize the technology size and ambition or all together forego the investment. Whichever way the potential to unlock livelihood and productivity opportunities is compromised. Capital cost is serious impediment to deployment and optimizes value of low-cost green technology

- *Physical access (non-discriminatory) to a water outlet in urban areas with a 30 minutes cycle and in rural areas within a distance of 2 km*
- *Sustainability of access (water resources, asset resilience, O+M cost coverage)*
- *Acceptable water quality*
- *Affordability (regulated but not more than 5% of household income as maximum)*
- *Reliability (> 12 h as minimum service hours)*
- *Right to have complaints resolved (participation / access to standardised complaint mechanism)*
- *Transparency and accountability (access to sector information)*

Figure 27: Criteria for Improved water supply services in Kenya (WASREB)

## 7.2. Cost effectiveness and benefits

The major benchmark of public investment is the cost effectiveness– the ratio of the total cost of an investment per unit of measure. For water supply, the measures of effectiveness is the change in improved water consumed per household, the change in average water usage as a result of the intervention, time savings or health costs and diseases averted by water interventions.

<sup>29</sup> Cost of borehole and solar pumping depends on depth and yield

Implementers continuously seek ‘appropriate’ standards as ways to deliver water supplies at lower capital costs. Common cost saving measures include reducing the capacity of the technology, change in specifications for example compacting of embankment soils, elimination or minimization of diameter or length of distribution pipelines, and lower cost of design and supervision inputs.

While it sounds reasonable to adjust standard criteria to suit specific circumstances in rural and peri-urban areas, in effect a reduction in the capital costs reduces the capacity of the scheme resulting in operation and maintenance problems. These problems often result in increased operation and maintenance costs.

Cost per capita is often the key criteria used to determine the feasibility of water scheme and technology. Consequently, due to lower population densities, rural and peri-urban supplies generally cost more per capita than it is the case for formal urban communities, and thus much more in the most sparsely populated rural areas.

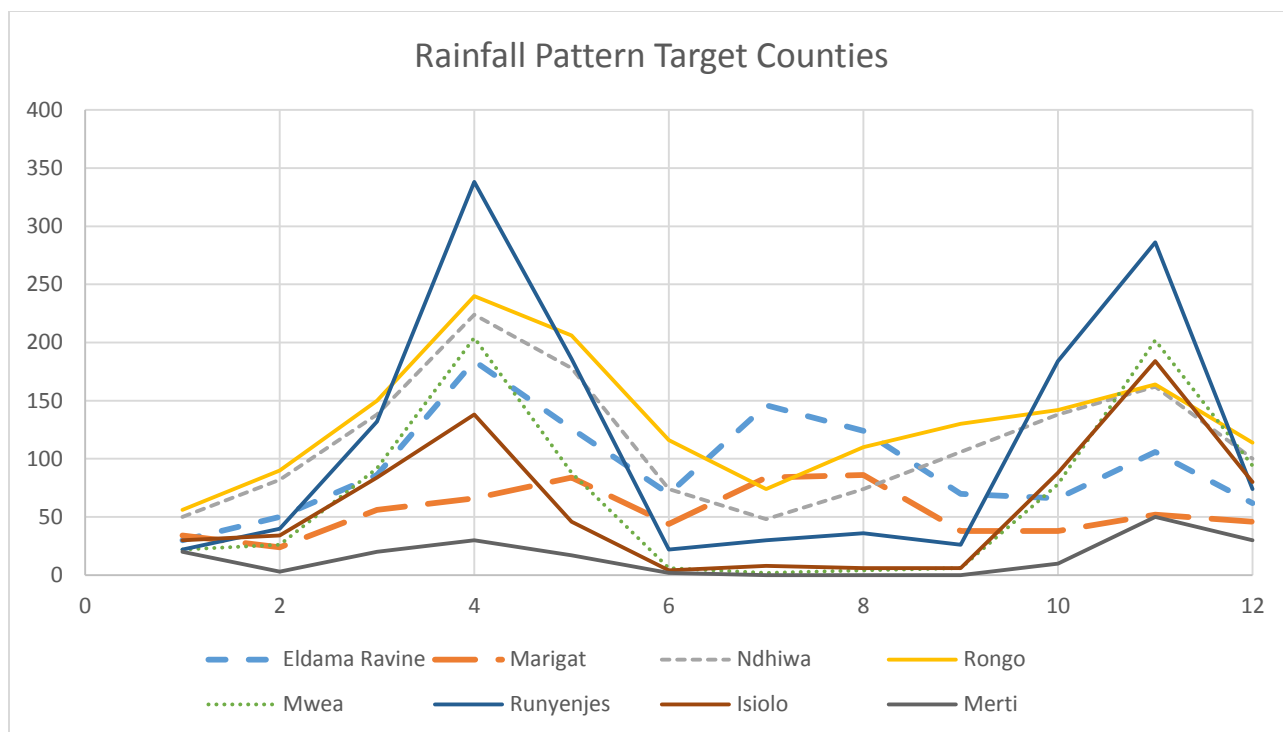
To demonstrate the requirement for effectiveness of technology deployment, consider a water supply system based on an area measuring 16 km<sup>2</sup> (4km by 4km), and theoretically place the technology point at the middle such that the furthest user is within 2km from the collection point. Assume this system delivers water need for domestic, livestock and irrigation uses. Table 28 shows the population density and average households that are possible within this area. This means that for a nearly equal investment size, and all things constant the technology would be more effective in Homabay in terms of cost and benefits per capita compared to Isiolo.

**Table 28: Population density in target counties**

County	Pop Density (inh/Km <sup>2</sup> )	HH size	HHs/km <sup>2</sup>	HHs in 16 km <sup>2</sup>
Baringo	50.4	6.6	7.6	122
Homabay	302.08	8.5	35.5	569
Embu	183.2	6.25	29.3	469
Isiolo	5.7	7.1	0.8	13

Another important factor in analysing the effectiveness of investment of low cost technology is the availability and reliability of water source on which solar or wind pumping technology are installed. In Table 18, it was explained that all solar and wind pumping systems observed during the survey were installed on boreholes. Therefore the safe yield and quality of boreholes is an important factor in evaluating and optimising cost effectiveness of low cost renewable energy technology. The distribution of safe borehole yields is shown in Figure 20 and how it limits effectiveness of solar and wind technology is discussed in section 6.2.1.

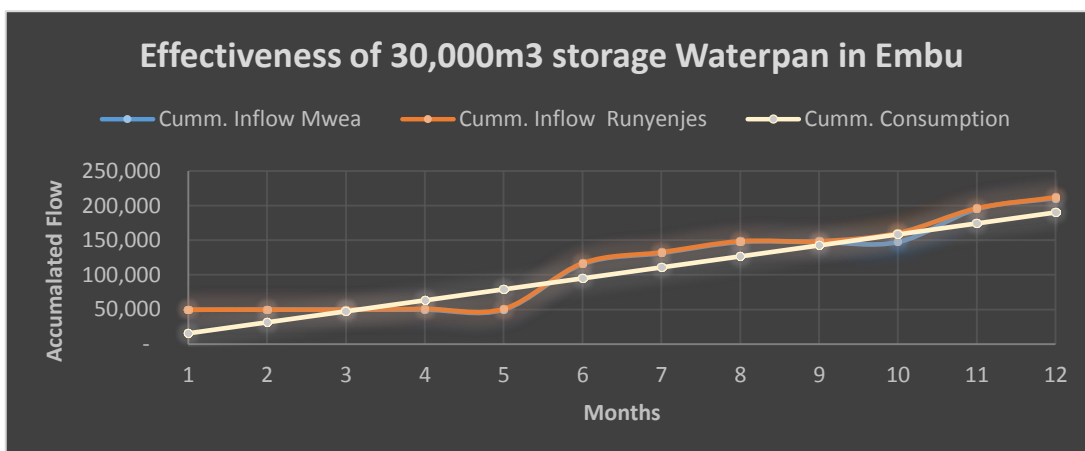




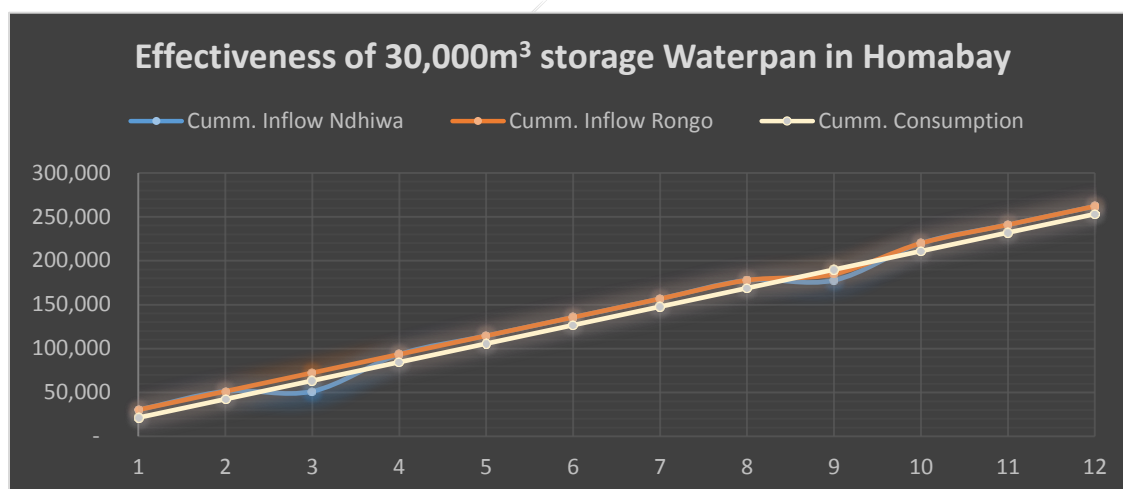
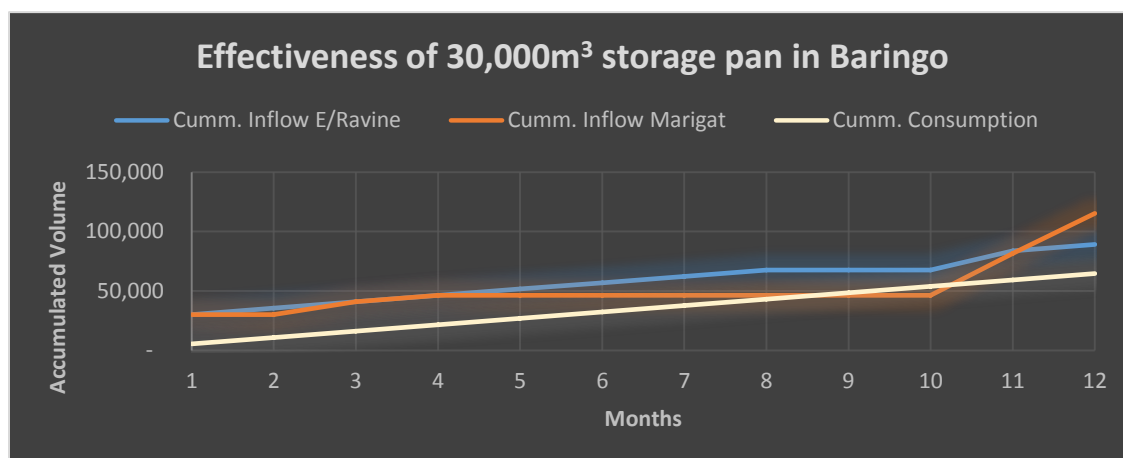
**Figure 28: Rainfall patterns in the target study areas**

Reliability of water pan is particularly determined by rainfall endowment. Figure 28 shows the annual rainfall patterns in the survey counties. Marigat and Eldama Ravine in Baringo have three rainfall peaks in April, May and November, while areas in Embu and Isiolo counties (for example in Runyenjes and Merti) have two sharp peaks in May and November. This is important because it defines the duration of the dry season and intervals of water pan replenishment. If investment is made to construct 30,000m<sup>3</sup> water pan in Baringo (Marigat and Eldama Ravine), Embu (Mwea and Runyenjes) and Homabay (Rongo and Ndiwa) and subject to pattern of uses describe in 6.2.1. The size of water pan in Embu (Figure 29) results in nearly 50,000m<sup>3</sup> water storage deficits, equivalent to 3-months demand. A water pan of the same size will provide water through the year in Eldama Ravine (sub-humid zone) and almost for the whole year in Marigat (Arid), Rongo (Sub-humid) and Ndiwa (Semi-Humid). Consequently, although Marigat has only 652 mm annually compared to 854 mm in Mwea and 1376 mm in Runyenjes, 50,000 M<sup>3</sup> water pan it is more effective in ensuring reliable source of water supply and time savings in Baringo than in Embu. However, the improvement in average water usage arising from the construction of the water pan is higher in Homabay than in Baringo.

Generally, the physical and financial size of technology investment, combined effect of population density, hence demand, and the length of dry season results are important determinant of technology effectiveness. In this case the optimum size of water pan to ensure supply throughout the year in Embu is 70,000m<sup>3</sup>, while 15,000m<sup>3</sup> in Eldama Ravine is sufficient to guarantee year round supply of water. In Homabay good rainfalls all year sustain water availability round the year but high population density means a high draw down of water and a low ability to withstand climatic shocks.



**Figure 29: Typical Performance of 30,000 m<sup>3</sup> Water Pan in Embu**



**Figure 30: Typical Performance of 30,000 m<sup>3</sup> Water Pan in Baringo (top) and Homabay**

### 7.3. Cost Benefit Analysis

The convectional way of analysing public investment is by means of cost-benefit analysis. The benefits (to water user) are the estimated reduction in travel time, health cost and improved livelihoods while the cost is the annual cost is the annualised investment and O&M charges. In the analysis Embu with population density of 183.2 person/km<sup>2</sup> and Baringo (50.4 person/km<sup>2</sup>) the cost benefit analysis is based on four types of uses/functions; domestic, livestock, small scale irrigation/function and disaster resilience.

Building on the preceding discussion there are 6 main likely scenarios, construction of either water pan or borehole equipped with grid electricity, solar PV or diesel generator. Improved scenario will entail the construction of distribution network, especially for transferring irrigation water.

In evaluating the benefits to domestic water supplies arising from low cost technologies, consideration is given to that fact that some people already have improved supplies, 45% for Baringo and 58% for Embu, (Water Services Regulatory Board (WSRB), 2016) and employment level 32% in Baringo and 91% in Embu. Daily wage of Ksh 400/per day is allocated on prorated basis to employed proportion of users who are employed. Average time for collecting water is taken as 4 hours daily and income benefit is allocated on a prorated basis. Distribution network is assumed to reduce the time taken to collect domestic water by 65% and 50% for borehole and water pan respectively. Potential of borehole water for domestic uses is reduced by 32% equivalent to salinity incidences in groundwater and water pan because poor physical quality is likely to restrain use. Whenever modern energy is supplied at source improved access a factor of 56% and 20% was applied for borehole and water pan respectively.

The average livestock holding in Baringo among the served users is 6 cows and 20 sheep/goat, while in Embu it is 0.83 cows and 1.5 sheep/goat. Based on these figures, the consumption is computed with priority allocation to domestic and livestock uses. Operating time is 8 hours for solar PV and 18 hours per day for grid electricity and diesel generator, which allows 4 hours daily for borehole recovery. Considering borehole yield of 5m<sup>3</sup>/hr gives daily maximum of 40m<sup>3</sup> for solar PV and 90m<sup>3</sup> for 18-hour pumping operations for diesel and grid electricity. Combined daily demand for domestic and livestock water uses in Baringo and Embu is computed at 54.5m<sup>3</sup>/day and 19.44m<sup>3</sup>/day<sup>30</sup>. The balance of water is available for irrigation but evidently, borehole sources have limited capacity to supply irrigation water and much more when fitted with solar PV, because of 8-9 hours operation time. Irrigation benefits are calculated using the price of maize, which is a common crop in Kenya, but it is possible that use of high value crop will give more favourable figures.

The capacity of the technology to mitigate drought disaster take into account the probability of drought occurrence, average of 3-7 years (see section 4.2), which is 5 years for Baringo and 7 years for Embu. The second consideration is the economic cost of drought in terms of death of livestock. This risk<sup>31</sup> is taken as 50% in Baringo and 10% in Embu

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<sup>30</sup> Though Embu has higher human population, improved water service level is significantly high, especially in the humid, sub-humid and semi-humid areas and therefore limited scope for domestic water demand

<sup>31</sup> Risk is a probability factor of frequency and size of the hazard. Both the frequency and intensity of drought is less in Embu and Baringo

The costs are derived from field synthesis data described in the preceding sections

#### **Planning factors for Baringo**

- Service area=16 km<sup>2</sup>
- Average borehole yield = 5m<sup>3</sup>/hour
- Average Households in the areas = 122 HH
- Required water pan = 15,000m<sup>3</sup>
- Capacity Solar PV installation and diesel generator = 10kVA
- Length of distribution network 16km
  
- Solar PV operating time = 8 hours daily
- maximum daily borehole pumping = 18 hours
- Average consumption per HHs = 125 lpd
- Employment rate = 32%
- Improved water supply = 40%
- Livestock = 6 cows and 20 shogoats per HH
- Consumption per livestock unit<sup>32</sup> – 50 litres/day
- Irrigated farm areas per household = 0.06 acre
- Average number of users doing irrigation = 15%
  
- Interests on capital =14%
- Assumed service life of infrastructure – 15 years

#### **Planning data for Embu**

- Service area=16 km<sup>2</sup>
- Average borehole yield = 5m<sup>3</sup>/hour
- Average Households in the areas = 469 HH
- Required water pan = 70,000m<sup>3</sup>
- Capacity Solar PV installation and diesel generator = 10kVA
- Length of distribution network 16km
  
- Solar PV operating time = 8 hours daily
- Maximum daily borehole pumping = 18 hours
- Average consumption per HHs = 125 lpd
- Employment rate = 91%
- Improved water supply = 80%
- Livestock = 0.83 cows and 1.5 shogoats per HH
- Consumption per livestock unit<sup>33</sup> – 50 litres/day

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<sup>32</sup> livestock Unit (LU) is equivalent of 3 traditional cows or 15 sheep and goats

<sup>33</sup> livestock Unit (LU) is equivalent of 3 traditional cows or 15 sheep and goats

- Irrigated farm areas per household = 0.06 acre
- Average number of users doing irrigation = 76%
- Interests on capital =14%
- Assumed service life of infrastructure – 15 years

**Table 29: Cost of technology by component**

Description of Component	Cost (Ksh )
Water pan (30,000m <sup>3</sup> )	9,060,000.00
Water pan (70,000m <sup>3</sup> )	21,140,000.00
Generator (10kVA)	1,200,000.00
Solar 10KW	1,950,000.00
Solar Pump and accessories	1,000,000.00
Electric Pump and accessories	750,000.00
Borehole, 200m deep	1,900,000.00
Distribution Network	6,400,000.00
Electricity Connection Charges	700,000.00
Gravel/Sand Filter	300,000.00

From the analysis in Table 30 and Table 31, it is observed that all the alternatives give positive benefit - cost (B/C) ratio. Boreholes fitted with modern energy, solar, diesel generator and grid electricity in that order, without distribution network has the highest return on capital. Borehole and solar PV installation gives the lowest annual cost of Ksh 1,165,823 while water pan with solar pumping, treatment filter and distribution system is the mostly costly alternative estimated at Ksh 3,822,556 and Ksh 5,789,288 for Baringo and Embu correspondingly. Detailed analysis capturing wider array of benefits for example health, education, horticulture and youth employment may end with different results. However, a B/C ratio does not in themselves provide sufficient information to make an economic choice among the alternatives. Further analysis of the additional benefit added by each incremental investment and the ratio of the increments of benefit to the corresponding cost is determined. Extra investment costs are justifiable whenever the resulting benefits exceed the extra costs, and the vice-versa.

Table 30 and Table 31 present the incremental B/C analysis of the different alternatives. Diesel generator and grid electricity compared to solar energy pumping cost more in terms of annual costs by Ksh 242,252 and Ksh 397,379 correspondingly but without any increment in benefits. Incremental B/C analysis in Baringo is less than 1 for all the alternatives compared with borehole and solar and therefore borehole and solar pumping gives best return in investment but in the case that borehole sources are limited because of low yield or salinity water pans equipped with solar pumping, treatment filter and distribution network are a better alternative. It is important to remember that this alternative is based on 15% of users utilizing water for small scale irrigation.

In the case of Embu, a combination of water pan, solar pumping, and treatment filter and distribution network is the best economic alternative, followed by a borehole fitted with solar PV and distribution system. The third best alternative is a borehole fitted with solar pumping without a distribution network. The better evaluations of distributed water supply systems in Embu come about because of the large number of users who utilize water for irrigation. The alternative of distributed supply from borehole sources is less efficient because of restrictions in the permissible abstraction.

The principle of ranking projects on the basis of economic analysis is important to ensure maximum return on investment. However, such rankings have to be reconciled with political pressures that encourage fair distribution of projects rather than maximisation of returns. Intangible factors such as the need to stimulate the economy within a region also indicate a departure from strict capital-budgeting rules.



**Table 30: Benefit-Cost and Incremental B/C Analysis for Low-cost technology in Baringo**

	Project Alternatives	Investment Cost	Opportunity cost	Annual investment charges	Annual O&M	Total annual project	Annual Cost	Annual Benefit	B/C	Incremental Cost	Incremental Benefit	incremental Benefit-Cost Ratio
1	No Project	0	8,500,356			8,500,356	-	-				
1	Borehole + Solar	4,850,000	2,090,104	789,623	376,200	3,255,927	1,165,823	6,410,252	5.5	0	0	0
2	Borehole + Diesel Generator	3,850,000	2,090,104	626,815	781,260	3,498,178	1,408,075	6,410,252	4.55	242,252	0	0
3	Borehole + Grid Electricity	3,350,000	2,090,104	545,410	1,017,792	3,653,306	1,563,202	6,410,252	4.1	397,379	0	0
4	Water Pan alone	9,060,000	3,992,163	1,475,049	240,000	5,707,213	1,715,049	4,508,193	2.63	549,226	-1,902,059	(3.46)
5	Borehole + Solar + Dist. Network	11,250,000	1,671,491	1,831,601	536,400	4,039,491	2,368,001	6,828,866	2.88	1,202,178	418,614	0.35
6	Water pan + solar	12,010,000	3,295,971	1,955,336	616,200	5,867,507	2,571,536	5,204,385	2.02	1,405,713	-1,205,867	(0.86)
7	Water Pan + Diesel Generator	11,010,000	3,296,471	1,792,527	1,021,260	6,110,257	2,813,787	5,203,886	1.85	1,647,964	-1,206,366	(0.73)
8	water pan + Grid Electricity	10,510,000	3,296,471	1,711,122	1,257,792	6,264,886	2,968,914	5,204,385	1.75	1,803,091	-1,205,867	(0.67)
9	Water pan + solar Pump + Distribution	18,410,000	2,318,976	2,997,313	776,400	6,092,689	3,773,713	6,181,380	1.64	2,607,890	-228,872	(0.09)
10	Water pan + solar Pump + Distribution + treatment filter	18,710,000	231,898	3,046,156	776,400	4,054,453	3,822,556	8,268,459	2.16	2,656,733	1,858,207	0.70

**Table 31: Benefit-Cost and Incremental B/C Analysis for Low-cost technology in Embu**

	Project Alternatives	Investment Cost	Opportunity cost	Annual investment charges	Annual O&M	Total annual project	Annual Cost	Annual Benefit	B/C	Incremental Cost	Incremental Benefit	Incremental Benefit-Cost Ratio
1	No Project	0	39,885,622	-		39,885,622	-	-				
1	Borehole + Solar	4,850,000	17,998,383	789,623	376,200	19,164,206	1,165,823	21,887,239	18.77	0	0	
2	Borehole + Diesel Generator	3,850,000	17,998,383	626,814	781,260	19,406,457	1,408,075	21,887,239	15.54	242,252	0	-
3	Borehole + Grid Electricity	3,350,000	17,998,383	545,410	1,017,792	19,561,585	1,563,202	21,887,239	14	397,379	0	-
4	Borehole + Solar + Distribution	11,250,000	14,490,400	1,831,600	536,400	16,858,400	2,368,001	25,395,222	10.72	1,202,178	3,507,983	2.92
5	Water Pan alone	21,140,000	33,882,642	3,441,781	240,000	37,564,424	3,681,781	6,002,980	1.63	2,515,958	-15,884,259	(6.31)
6	Water pan + solar	24,090,000	28,074,884	3,922,067	616,200	32,613,152	4,538,268	11,810,738	2.6	3,372,445	-10,076,501	(2.99)
7	Water Pan + Diesel Generator	23,090,000	28,074,884	3,759,258	1,021,260	32,855,403	4,780,519	11,810,738	2.47	3,614,696	-10,076,501	(2.79)
8	Water pan + Grid Electricity	22,590,000	28,074,884	3,677,854	1,257,792	33,010,531	4,935,646	11,810,738	2.39	3,769,823	-10,076,501	(2.67)
9	Water pan + solar Pump + Distribution	30,490,000	19,359,194	4,964,045	776,400	25,099,640	5,740,445	20,526,428	3.58	4,574,622	-1,360,811	(0.30)
10	Water pan + solar Pump + Distribution + treatment filter	30,790,000	1,935,919	5,012,888	776,400	7,725,207	5,789,288	37,949,702	6.56	4,623,465	16,062,463	3.47

#### 7.4. Cost Recovery

Operation & Maintenance (O&M) cost are recurrent costs which include spare parts and maintenance, replacement of equipment, electricity and fuel charges (if applicable), abstraction charges and labour. Table 32 shows the source of operation and maintenance finances. In 58% of the cases, the user communities cover O&M costs through monthly contributions or through the revenue collected. The role of donor, NGOs and private actors in post construction support is negligible.

**Table 32: Sources (instances) of O&M Finance**

Source of Funds	Frequency	Percentage
Donor	2	2%
Government	18	19%
Community /Revenue	36	58%
Private	4	4%
Others	17	17%
<b>Total</b>	<b>97</b>	<b>100%</b>

Table 33 shows the synopsis of total and average revenue and cost for water supply system. It is a summation of total costs and revenue from all the points surveyed. The O&M coverage is 52%, which means that technology points are operating in deficit. Provision for maintenance is low at 22% of the O&M cost. The cost of energy is considerable, representing up to 50% of the O&M costs and up to 96.5% of the revenue collected in some schemes. This situation leaves the water management committees with nothing to maintain or use to expand the system. Solar and wind have low recurrent costs and potentially their deployment will free more resources towards maintenance. It was found that O&M cost recovery is uneven, either too much is raised (sometimes attracting dishonest caretakers) or too little is raised, which is insufficient for maintenance. Either way this tends to compromise the sustainability of technology and water supplies. The manner in which revenue is collected and managed is thus critical to the success and sustainability of the technology deployed.

**Table 33: Synopsis of Revenue and Costs (Ksh)**

Item	Fuel (1)	Salaries (2)	Electricity (3)	Transport (4)	Misc (5)	Maintenance (6)	Revenue (7)
Total cost for all technology points	802,000	488,000	447,200	131,450	66,000	548,350	1,294,700
Average cost per Technology Point	9,547	5,810	5,324	1,565	786	6,527	15,413
Average Operating Cost (1+2+3+4+5)	23,032		All values in Ksh				
Average Maintenance cost (6)	6,527						
Average O&M Cost	29,559						
Average Revenue	15,413						
O&M Coverage (cost/ revenue)	52%						
Energy Cost to O&M /Revenue	50%/ 96.5%						
Ratio of Fuel Cost to O&M / Revenue	32% / 62%						
Ratio of Electricity cost to O&M/Revenue	18%/ 35%						



Table 34 tabulates the instances of various recurrent costs and revenues in the surveyed technology points, taking into account only those points where the particular costs were incurred. This provides a more realistic average cost per point for purpose of cost-benefit analysis. What stands out is the proportion of fuel and electricity cost compared to revenue.

**Table 34: Monthly revenue, Operation and Maintenance (Ksh )**

Cost	Frequency	Percent	Average Cost (Ksh)	Lowest (Ksh)	Highest (Ksh)
<b>Fuel</b>	17	20.2%	45,575	6,000	240,000
<b>Salaries</b>	40	47.6%	13,350	1,500	46,000
<b>Electricity</b>	15	16.7%	32,643	1,000	15,000
<b>Maintenance</b>	54	64.3%	6,180	50	70,000
<b>Revenue</b>	42	50%	38,075	1,000	35,000

Tariff setting is an important area of focus to ensure cost recovery and is ought to be established considering the water source and cost of sustaining service. However in a community managed system tariff rate is based more on common practice than on a precise calculation of a tariff that generate revenue for a full life cycle recovery. It was found that water tariffing varies from scheme to scheme but the majority applied 'pay per use' on the basis of 20 litres jerrycans. User charges were between Ksh 2 and 5 per 20 litres and Ksh 100 to 250 per M<sup>3</sup>, which is considerably higher compared to average tariff charged by formal water services providers (isiolo - Ksh 81, Embu - Ksh 64 and Baringo – Ksh 47). Few operated on flat use charges ranging from Ksh 50-400 per month.

In most cases it was found that the tariff doesn't include the depreciation cost of the water system, the replacement of devices with relatively short life-spans (e.g. motorised pumps, electricity panels, smaller tanks) or the energy and replacement of capital infrastructure. Such components as improvement of water sources or use the savings to extend the network or the entire notion of care management is neglected leading to total collapse of the system after sometime. This may explain why most infrastructures were found to be less than 10-years old. Considering that capital components have a life-time of 30-50 years, it might not make sense that a community save for replacements in 50 years' time. As a result, a demarcation between what is possible with community finance and where there is a need for public investment should be drawn.

One case example is found in Embu, where Grundfos rehabilitated 42 predrilled boreholes in 2012. The installation was linked to a 10- year service contract and included pumps, solar PV, 10 m<sup>3</sup> plastic storage tanks and a prepaid system. The cost of installation was approximately Ksh 3.5 million while the average revenue is Ksh 20,000 per month charges at Ksh 100/m<sup>3</sup>. Grundfos levies Ksh 216,000 annually as O&M fees. The users reported very quick attention to operational faults, normally within hours of occurrence. All maintenance is done by Grundfos but a local technician does the operations with no pay. Despite the technology assisting the community to obtain water easily, the users were dissatisfied with the performance of the system in the cold season, owing to poor irradiation affecting solar energy

generation. Users had also expected the scheme to provide them with water for irrigation which not been factored in the design of the system. Moreover, community members were dissatisfied that Grundfos retained the revenue collected as opposed to the past whereby they collected and managed the point.

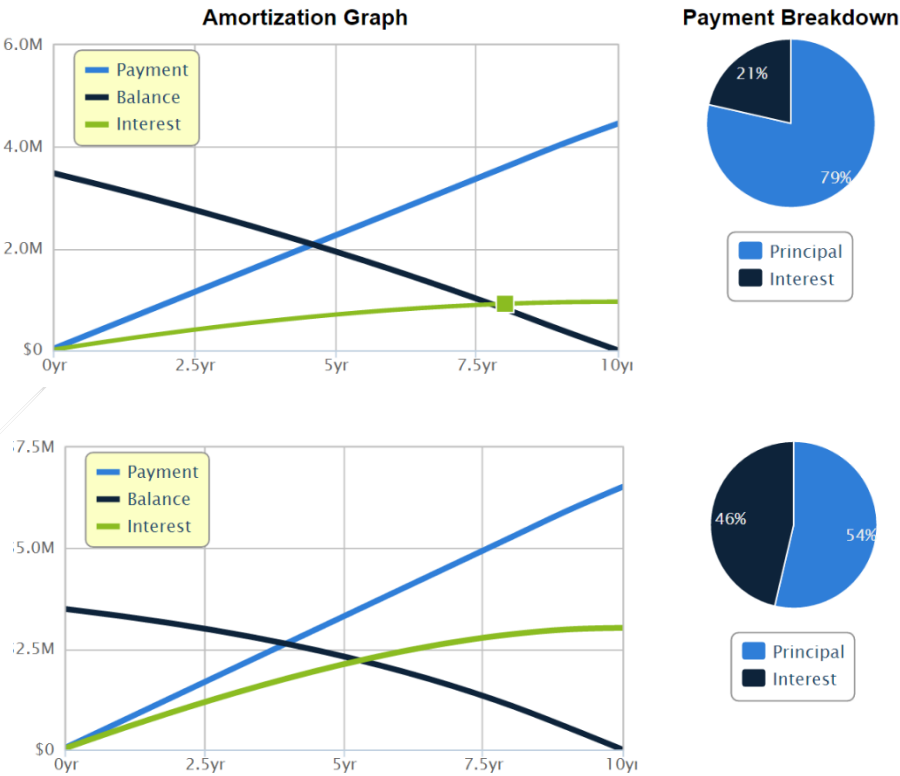
The second challenge was the absence of local representation of Grundfos. This presented challenges for example in the replacement of lost prepaid cards, without which users would not conveniently collect water. The other challenge was that benefitting communities were restricted to develop the system during the contract life with Grundfos. Many users considered for example adding small pipe networks to the existing system necessary to reduce the water collection distance, as well as to limit congestion at source. Most users also expected the system to provide water for irrigation but this had not been factored into the design of the system, as the installation of individual metered connections was deemed too expensive.

This Grundfos experience provides evidence that communities can afford annual maintenance charge. Nonetheless the model is found to work best where population density and consumption are high enough to meet cost recovery.

Grundfos has recently started another 9 pilots of long-term equipment lease (8 in Meru County and one in isiolo). One of the evidence coming out from the experiment with these pilots is that sales revenue

can finance professional service and maintenance of water projects. The critical maintenance challenge was the escalating cost of valves and the cost of maintaining GSM communication.

Grundfos pilot initiatives illustrate the willingness of communities to engage with skilled service providers for capital and maintenance improvement. One of the challenges which need to be addressed is the strong sense of ownership by the community, and the resulting unwillingness to accommodate private



**Figure 31: Amortisation of Ksh 3.5 Million investment debt at 5% (top) and 14% (bottom) interest rate**

operators. Another challenge experienced with this model is the community perception that the technology supplier is making huge profits from revenues. This is not necessarily the always case. Poor GSM network coverage in some locations causes delayed response to failure report by the maintenance technicians based in Nairobi.

To rate the fairness of the maintenance fee being charged by Grundfos it's evaluated against the cost commercial debt. Figure 31 displays amortisation of commercial investment loan of Ksh 3.5 million (equivalent to Grundfos capital cost in Embu). At the prevailing interest rate in Kenya of 14%, the community would make monthly repayments of Ksh 54,343 over 10 years. At a lower interest rate of 5%, repayment goes down to Ksh 37,122 per month. With a 125 lpd domestic consumption per household at 14% and 5% interest rate, this means that the scheme need to supply a minimum of 145 and 99 households respectively (at Ksh 100/m<sup>3</sup>) in order to afford capital repayment. If the salary cost of Ksh 13,350 is included, the minimum number of households required to break-even is 180 at a 14% interest rate and 135 at an interest rate of 5 %.

Consequently, rising consumption will increase viability of small water supply network. Small supply network connected to individual consumer homes may not be viable

unless located in high-density population areas or otherwise the cost of connection is subsidized or paid by the users themselves. Finally, suitable financing mechanisms are needed to lower repayment burden and encourage uptake.

### Box 3: Garbatulla Town Water Supply

Garbatulla town Isiolo County is a small urban centre with a population of about 5,500. The water supply is obtained from 4 connected boreholes. 2 boreholes are powered by combination of grid electricity and a stand by diesel generator, one by diesel generator and the forth using solar PV. The infrastructure was financed by the government. Grid electricity experiences frequent power outages which cause damage to electric pump motor. The diesel generator installed in 2015 is expensive to maintain and most of the time it is not operational due to lack of fuel. During the field study, the diesel generator was not operational due to equipment breakdown.

Although each household pay 400 Ksh /month for the water use, the revenues are not sufficient to cater for operation and maintenance. Often times when the water supply is limited to water obtained from the solar PV system. Frequent downtime translates to low sales, which together with high cost of electricity and fuel implies that the utility relies heavily on the county government support for operation and maintenance.

#### Challenges

- High electricity cost
- High Fuel cost
- Low O&M skills to handle diesel generators
- Dilapidate distribution system (1972)
- Low water storage capacity (storage tanks)



## 8. Analysing Technology Access and impacts

*This section explores the diversity of the beneficiary communities and the social acceptance of the technologies, and how the communities interact with different technologies to ensure the sustainability of water supply.*

Understanding the scale and reach of the management model of the technologies plays an important role in comprehending community assimilation with the technology. Community-based management remains the principal service model of rural water supplies delivery. This is true across all the four counties surveyed in this study. It was found that the role of the private sector in rural and peri-urban water provision remains limited and despite its shortcomings, community-based management remains the dominant approach for water supplies in the target counties.

In two-third of the cases where the technology was owned by government, the system was either driven by gravity or grid electricity. In 72.4 % of the cases surveyed, the technology was managed by a community committee compared to 5.7% for private and licensed water service operators.

**Table 35: Technology Operators**

Technology Operators						Total	
		Embu	Baringo	Isiolo	Homa Bay	Frequency	Percent
Operator	WSP	1	2	1	1	5	5.7%
	Management Committee	15	18	17	13	63	72.4%
	Individual	5	0	0	2	7	8.0%
	Private	3	0	0	2	5	5.7%
	CBO	3	0	3	1	7	8.0%
Total		27	20	21	19	87	

Beneficiaries' communities contributed to 19.5% of capital and 58% of the operation and maintenance cost. Consequently, it is evident that the communities had the greatest responsibility in post-implementation of the technologies and provided significant contributions to investment decisions. In situations where they do not have the skills or the experience required this constitutes a key challenge. Therefore, management of the selected technologies cannot be neglected when addressing the social viability. For technologies to be feasible it is important that take into consideration community preferences, equity considerations, perceived ease of application, and reliability at different times of the day/year and in different climatic conditions.

### 8.1. Preference of water supply technology

Understanding community preferences plays a key role in defining the social viability of green technologies. It was found that technology preferences are based on a number of factors such as the potential to reduce distance to water source, the easiness to use the technology, the acceptance of the selected technologies by different actors, water users' perception of technology reliability and the ability of the technology to meet the needs of the users. These factors may have a positive effect on the individual opinion on preferred water source and technology.

Few cases of small supply systems supported by solar energy were observed during the study.<sup>34</sup> These demonstrate the potential to increase convenience and reduce the effort required to collect water through the use of solar water pumping systems.

It was found that due to the high cost of operation and maintenance for diesel and grid electricity systems, communities are opting for green technologies that are considered easy to manage, operate and maintain such as solar system. For instance in the case of the Muiya borehole water supply project in Baringo County, the management committee reported to collect revenue of Ksh 160,000 both from the individual connections and from those who collected water from the source. On average the committee used Ksh

100,000 for electric bills, Ksh S 20,000 Ksh for maintenance and KshS30, 000 for salaries per month. The revenue collected and the operation and maintenance costs are considerable in the dry season. In the dry season the revenue collected is Ksh 200,000 (150,000 Ksh used for electricity bills and Ksh 50,000 for maintenance). The variation in revenue and operation and maintenance cost across season is due to reliance of a roof catchment system. The committee reported that it was becoming difficult to maintain the system and had approached the county government with a proposal of upgrading the system with solar power. This example shows that the high cost of maintaining diesel pumps and electricity systems is a strong parameter for community preference in favour of solar PV.

#### Box 4: Case of Rural Water Supply Network

The Atuota Group in Kipsing in Isiolo County was initiated in 2014 as a self-help group comprising the Samburu and Turkana cultural-ethnic groups. The project aimed at improving water supplies for domestic and irrigation uses. In 2015, Water Services Trust Fund (WSTF) upgraded the borehole from a diesel to solar water pumping system. Until then, the borehole was powered through the use of Diesel pumping systems. The community reported high running costs inhibited their ability to obtain water not only for irrigation but also for domestic use. Further, WSTF assisted in developing of water kiosks and distribution of pipelines from the water source to the kiosks. The solar water pumping system formed a mini- network providing water to;

- i. 5 Water Kiosks
- ii. 1 Health centre
- iii. 1 Catholic mission
- iv. 1 Boarding school with 400 students
- v. 1 Secondary school with 200 students
- vi. 1 General service unit
- vii. 7 Individuals connected (paying Ksh 7000 for connections)

The revenue collected at this point is Kes 3000 and Kshs 6000 during wet and dry season respectively. Every household was expected to pay Kes 50 per month for their domestic water use and Kes 100 for their animals. Towards the end of 2015, violence broke out forcing the Turkana community out of the area and the water supply was destroyed. Destruction of the water supply limited the community ability to obtain vegetables at ease and at a cheaper rate.

#### Lessons

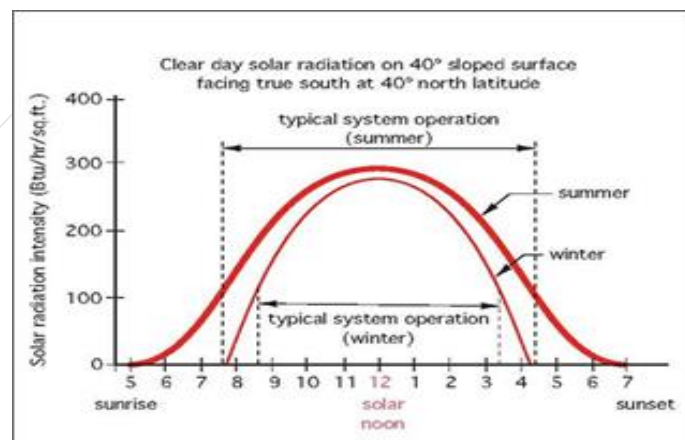
- i. Solar water pumping system can be used to distribute water to areas far a part through a mini-network
- ii. Solar system can support multi-uses of water
- iii. Community-based management continue to impact on the sustainability of rural water supplies

<sup>34</sup> *Chepchamus borehole in Baringo connecting 25 households, Garbatulla water supply in Isiolo County connecting serving Garbatulla North town and part of Garbatulla south, Radat in Baringo powered by diesel engine to supply water to 9 kiosks scattered in various area and solar powered boreholes in Kipsing, Isiolo serving 5 water kiosks scattered in various areas.*

It was found that there is application of wind energy in all four counties. Knowledge gaps with regards to the potential of wind technology were reported to impact on application of wind energy. Compared to solar, wind pumping systems are labour intensive to maintain. Moreover, it was found that the systems are abandoned by the communities because of limited accessibility to spare parts. Most of the wind mechanical systems visited have been replaced by solar, electricity and diesel systems. In Isiolo County, the Manyatta Zebra water supply project was initially powered using mechanical wind water pumping system. But due to constant breakdown and the time it took to address breakdowns, community approached the county government for funds to rehabilitate the borehole and equip it with solar pumping systems instead. This is not unique to Isiolo County only, as observations and interviews in all the four counties showed that wind energy were gradually being replaced by solar systems.

Hand pumps are often considered to be the most simple and economical system, high physical exertion for pumping water, limited access to spare parts, limited borehole depth (max 90 m) and yields affect the preference of the community towards this system. As a result, it was found that most of the hand pumps across the four counties are being replaced by solar pumping systems. Solar technology is considered to be free of effort in terms of operation, maintenance, and management, which make solar technology the preferred solution for water pumping in the surveyed counties, compared to other discussed technologies.

Reliability of technology from a user perceptive is depicted by the effectiveness of the technology over extended period of times in a day and across different climatic conditions. On average, all the technologies surveyed work during 8 hours in a day. During a cloudy day, which specially occurs in the wet season, there is less available energy from the sun to convert into electricity than in the dry season when the sun intensity is higher (Figure 328). In all the counties, solar systems had been coupled with a storage tank, which enables constant water supply throughout the day. The storage tank thus complements water supply in cloudy days, but is small in size and not based on actual demand. In contrast, diesel and electricity are not subject to seasonal fluctuations.



**Figure 32: solar radiation in season by hour of day**

The community preferences for water pans were greatly affected by the poor quality of water stored by this technology. Water pans are largely preferred for other productive uses as compared to domestic use. As discussed in section 6.2.1, many water pans retain water for a limited period and are therefore not reliable for constant water supply throughout the year. Consequently, community preferences and choice of green technologies are also affected by the number of working hours of the technologies and seasons, as well as by the quality of water obtained.

## 8.2. Technology uptake

In all the four counties the uptake of solar technology for water pumping is considerably high compared to others methods. It was found that the uptake of solar technology has been influenced by a decline in the cost of PV systems in recent years. Furthermore, various stakeholders such as the county government and NGOs are championing for solar water pumping system due to its ease in management and maintenance. 22 out of the 27 solar pumping systems visited were installed in the year 2010 onwards, with only one being installed between 1990 and 1999. In contrast, there has been a decline in installation of diesel pump in recent years. Between the year 2000 and 2009 a total of 7 diesel pumps were installed, as compared to 4 from 2010 and onwards. For grid electricity, the number of installed electric pumps have increased between 1990 and 2010 (3 visited points were installed between 1990-1999, 6 between 2000 and 2009, 7 between 2010 and onward). The increase in the number of electric pumps in recent years can be attributed to increased grid connection by the government's rural electrification programme.

The decline in the cost of solar systems and limited need for maintenance has contributed to significant uptake of these systems as reported by the local integrators of solar systems. The average current cost of solar module/watt is Ksh 100 in Kenya. Cumulative solar sales in Kenya (since the mid-1980s) represent more than 200,000 systems, and annual sales growth has regularly exceeded 15% over the past decade (Jacobson, 2006). The growing availability of solar water pumps at a reduced cost therefore offers a viable alternative to water supply systems which depend on grid electricity and diesel.

Various technology intermediaries such as the county government and NGOs have in recent years increasingly adopted the use of green technology, as compared to conventional methods. For example, the county government of Baringo reported that the county has been upgrading the diesel powered pumps and hand pumps with solar system since 2013. 50% of boreholes in Baringo County are currently running on solar energy. As reported across the four counties, long lifespan (20 years) of solar technology and minimal running costs have enabled communities to operate and manage the systems more easily. The county governments and NGOs reported that they have stopped giving fuel subsidies to the communities. Without fuel subsidy, many of the diesel generators are no longer in operation. In recent years, World Vision has reported that the organization is no longer installing diesel powered technologies for water supply due to high cost of operation and maintenance and the heavy reliance of fuel subsidies by the communities. Table 14 show that of the sampled water sources 34% lacked modern energy for pumping (21.2% using buckets and 11.7% hand pumps), which reflects a potential demand for solar systems.

Water pans have been taken up well in semi-arid and arid area firstly, water pans were intended to be for livestock but due to erratic rainfalls, groundwater salinity and lack of alternative sources, communities in the arid and semi-arid regions have also adopted them for small scale farming and domestic use. Nonetheless, water pans are not well-managed, as they are mainly viewed as alternative sources during the dry season. This has greatly affected their service life as most of the observed pans in all the four counties are drying up due to high siltation. Despite being considered suitable storage technologies for the dry season, their performance is limited when the water demand overcomes their



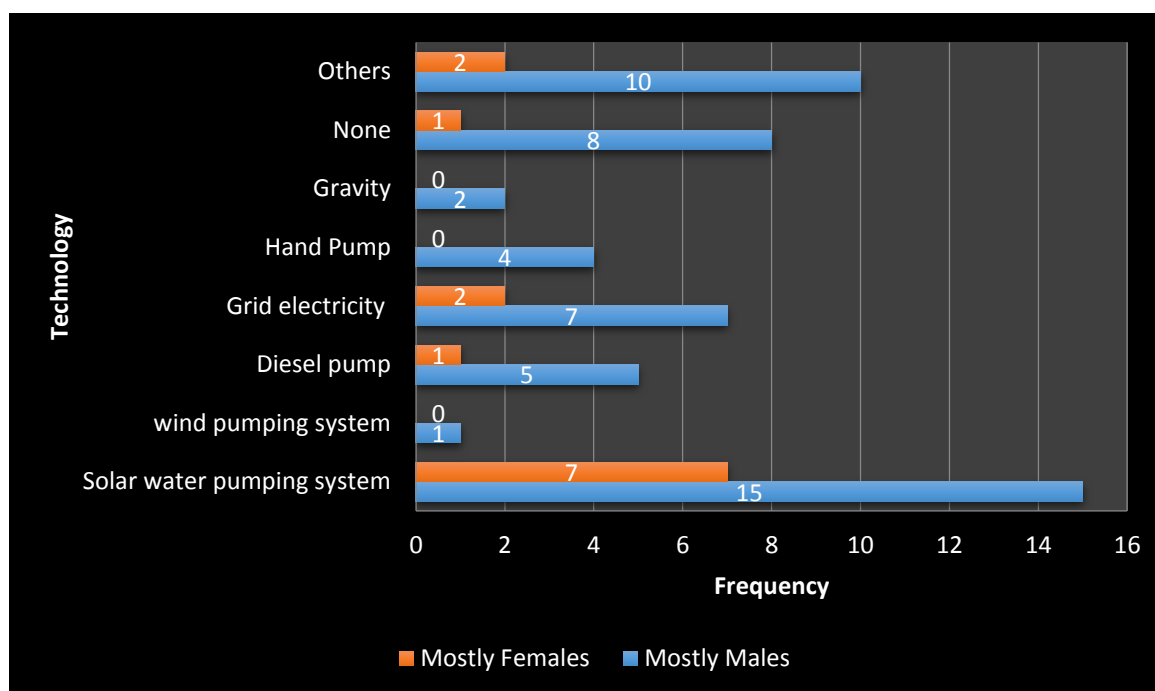
capacity. Moreover, due to high evaporation rates in arid and semi-arid areas, water pans are unable to retain water in the dry season.

### **8.3. Social marketing and equitability**

Socially viable technologies must be able to promote equitability and social marketing for sustainable water supply. Equitability in water supply implies that benefits are realised by all social groups and that the cost of water is favourable and equitable for all. 'Favourable' implies that the cost of water should cover the essential cost of the system and 'equitable' implies that each customer should pay their proportionate share of the cost. It was found that water pricing in rural areas does not provide an equitable and fair platform for the various groups within the community. Poor people who cannot afford having an individual piped connection pay more than users who are connected, despite an equal contribution to capital costs. For instance in Baringo County (Chepchamus Community Water Supply), households with connection were charged Ksh 300 per month for the water consumed with an unlimited access to the type of water use, whereas individuals without individual piped connection were charged Ksh 250 per m<sup>3</sup> with access limited to domestic and livestock uses. This can also be compared to the Ksh 94 per m<sup>3</sup> charged by Nairobi City Water & Sewerage Company Limited (NCWSC) for the city consumers. This is an indication that not only do the poor pay more for water but they also pay a higher price in the form of time lost due to long distances to water points, and the resulting negative effects on productivity and health.

Looking at gender equity, solar water pumping systems have provided a platform for men and women to interact with the system on an equitable basis. Figure 33 shows 15 out of 22 surveyed solar systems were being mostly managed by men. The participation of men and women in the operation and management of solar technology in an equitable manner enables them to become drivers, as well as beneficiaries of the benefits associated with these systems. Equitable interaction of both genders allows for women and men's concerns and capabilities to be integrated in operating and managing these systems. This creates an equal platform for sharing the benefits accrued. World Vision reported that the benefits of the solar systems to men include reduced distances to water points. This means that men in arid and semi-arid areas are able to spend more time with their family, as opposed to when they were forced to walk long distances in search of water and pastures. Moreover, their participation in effective water management enhanced development of social networks and in some cases pooling of social capital. The pooling of social capital has developed cohesion and a platform based on investment initiatives. Similarly, the use of this technology has empowered women economically, as they are able to engage in small scale farming. It has also enabled them to have more time to engage in productive activities and improved hygienic practices, which has resulted in a significant improvement of the health of the family.





**Figure 33: Gender Representation**

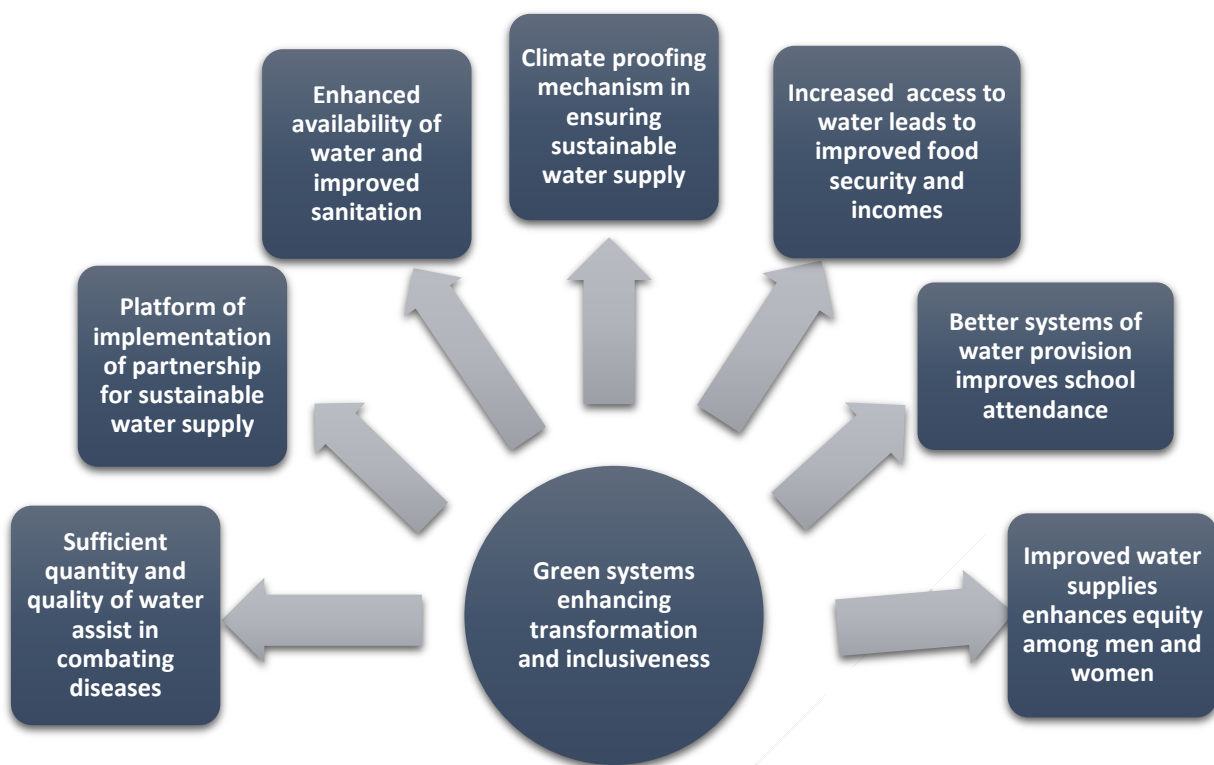
Interestingly, it was found that youth have not been directly involved in the operation and management of rural and peri-urban water supplies, in spite of the fact that young people are often considered dynamic, forward looking and in the best position to benefit from innovative solutions. In fact, interviews with youth indicated that the use of solar pumping systems has limited their productive gains. For instance, interviewed youth in Kipsing (Isiolo County) reported that the ability of solar systems to enhance water supply had in recent years limited the benefits they earlier accrued. Initially, they were involved in transporting water to the community at a cost of Ksh 20 per 20 litre jerrycan. In areas where roads were inaccessible, youth were involved in ferrying diesel to be used for water pumping by motorbike. However, the various actors interviewed in the counties could not quantify the impacts of solar water pumping system on youth. The main benefits of improved water supply to youth cited include employment opportunities (operating water kiosks) and training in artisan courses. It is critical to the sustainability of water supplies that water benefits are realised by all social groups within a community.

Another finding is that solar water pumping systems have been adopted in schools and health centres. Adequate water supply has supported the creation of child friendly environments in learning institutions. These sentiments were shared by World Vision Kenya indicating that improved water supply in learning institutions has generated considerable benefits in terms of improved child health, increased school attendance and performance. Moreover, it was found that the use of solar energy for water pumping and institutional lighting in the health sector has been adopted in the counties. Davis and Shirliff indicated that they are working with Population Services International (PSI) to supply solar systems for lighting in 250 health centres in Kenya, where PSI acts as a loan guarantor on behalf of the health centres and the amount obtained from the loan is paid directly to Davis and Shirliff. PSI then

enters into agreement with the health sector on loan repayment mechanism. Similarly, Windrock international has the same arrangement with Davis and Shirtliff to provide solar for irrigation. The ability of solar water pumping systems to support other services such as education and health provides an impetus for deployment of low cost technology for sustainable water supply.

#### **8.4. Summary - Acceptability and potential for transformation and Inclusiveness**

- i. Social acceptance of technologies is recognised as an important issue in shaping the widespread implementation of green infrastructure for sustainable water supply, especially in underserved areas.
- ii. Solar water pumping systems have been widely accepted by communities in all the four counties. Their acceptability is evidenced by the low effort required for their operation and maintenance and their easiness of use. Furthermore, these technologies provide an equitable and fair platform in terms of the benefits shared by all social groups. In recent years, solar water pumping systems continue to be the preferred technologies among community members and other stakeholders.
- iii. Water pans are largely considered to be alternative water sources, particularly during dry seasons. The poor quality of water pans impacts on their acceptability among the community members. Water Pans can play an important role in supporting other productive uses supplementing water obtained from boreholes that largely support water for domestic use. It is important that larger investments in water pans are considered to allow maximum realization of benefits.
- iv. The use of green technologies for water supply shows that economic and social objectives in water supply are not only compatible but they are also complementary. While green technology drives poverty reduction it may simultaneously improve anticipated social outcomes. The use of green technologies reduces the burden for women and children, who are mainly responsible for fetching water, which gives them more time to spend on school and other income generating activities. Furthermore, poor and marginalised groups in the four counties share the benefits of solar systems through improved human welfare, enhanced efficiency, increased resilience to climate shocks and continued job and business creation through enhanced water supply.
- v. Green technology systems continue to offer vital opportunities to leverage stakeholders' linkages through working collaboratively with other players in the water sector. These linkages play an important role in developing a human capital base of skills, knowledge and entrepreneurial enthusiasm that will promote sustained water supply. Involvement of various actors in water pans and solar system investments ensure that water supply interventions are holistic, effective and sustainable.
- vi. Figure 34 summarises the potential of solar systems in promoting transformation and inclusiveness through enhanced water supply.



**Figure 34: Social-economic potential of green technologies**

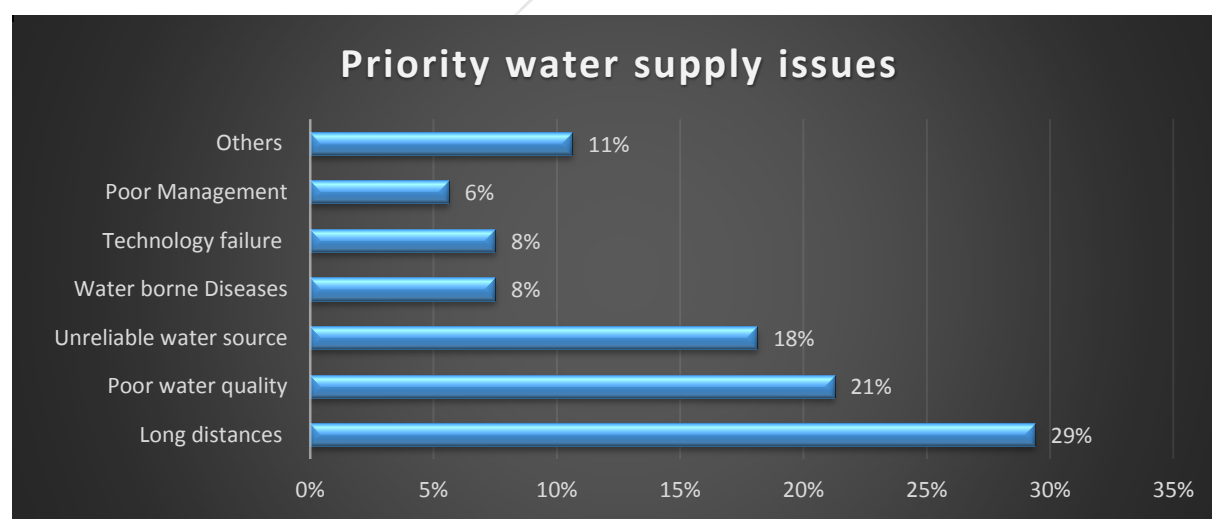
## 9. Technology Risk and Sustainability Analysis

*Sustainability pertains to multiple aspects of water supply, including institutional, social, technical, environmental and financial dimensions. This section examines the link between low technology base and poor functioning of water supplies and the potential obstacles to the deployment of selected technologies.*

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### 9.1. Sustainability context of selected green technologies

The challenges of managing low cost technology in areas of increasing competition for scarce water resources are daunting. Maintaining the integrity and sustainability of water systems through the use of methods that influence poverty levels and take explicit account of the uncertainties and risks of climate change is an even bigger challenge. The overall water service development goal is to achieve universal coverage by 2030 to ensure population wellbeing including health, resilience, direct employment and other means of livelihood. Currently, the constrained ability to develop and sustainably manage water supplies in rural and peri-urban areas is a key challenge. As a consequence water quality has remained poor and water sources are drying up, limiting efforts to increase spatial coverage. Figure 35 shows the key challenges users experience with water supply in the target countries, including long travel distances to water points, which is linked to low coverage (accounting for 29% of the issues mentioned), poor water quality (21%), water borne diseases (8%), unreliable water sources (18%), technology failures (8%) and poor management (6%). The combined impacts of these challenges in rural and peri-urban areas are persistent cases of poor health, vulnerability to seasonal climate variability and communities that are trapped in cycles of poverty. Figure 35 illustrates the contextual technology risks and underlying causes for unsustainable water supply management and the limited ability to expand water use benefits. These include poor governance and support services, coupled with the socio-economic situation of communities, climatic and environmental conditions and a low technology base.



**Figure 35: Most important water supply issues**

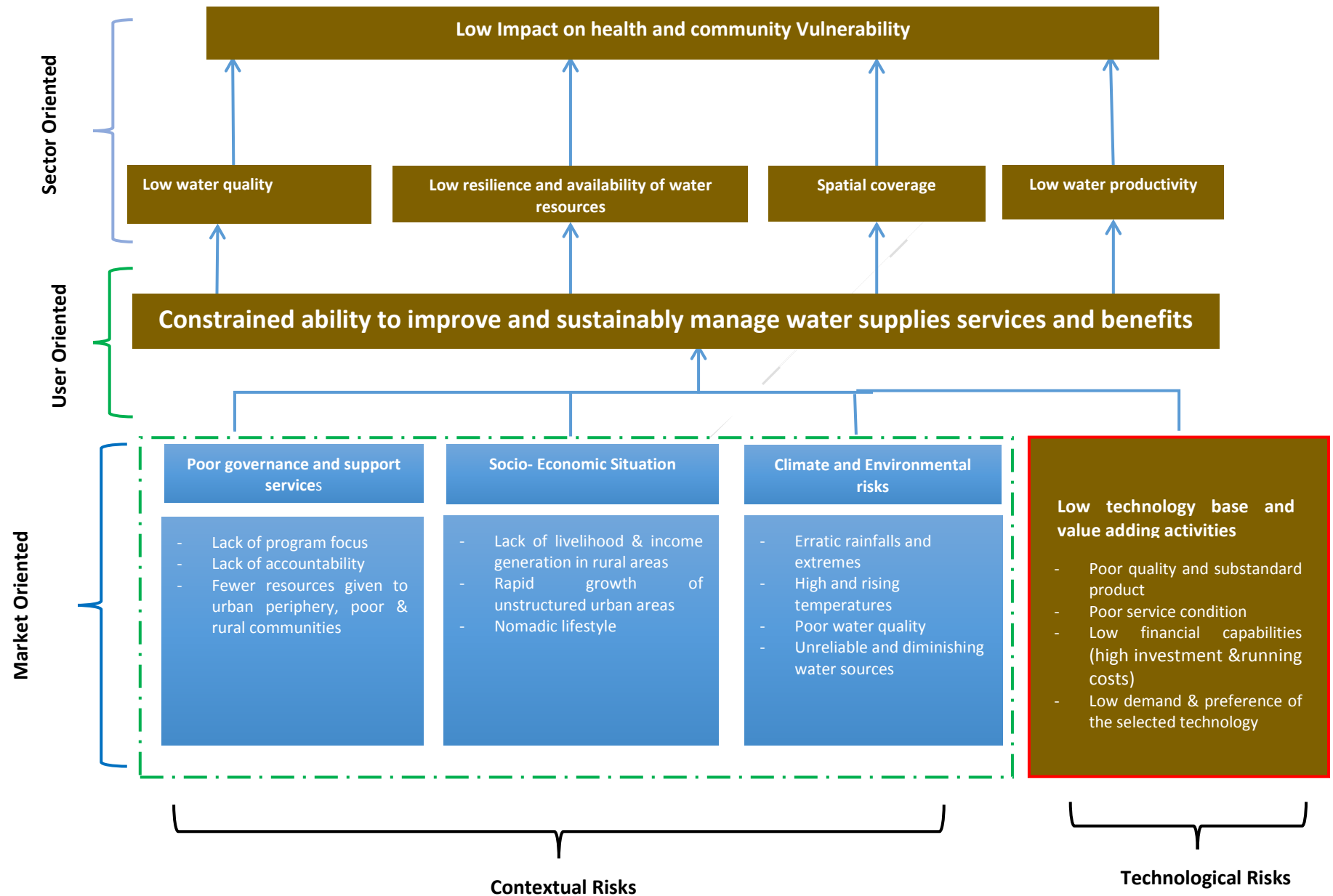


Figure 36: Problem Tree on constrained ability to improve water supplies

## **9.2. Technology Risks**

### **9.2.1. Poor quality and substandard products**

Poor quality and substandard products continue to inhibit progressive uptake of green technology in Kenya. Proliferation of sub-standard solar energy technologies and equipment continue to affect the technology base, particularly in the water sector. Rapid expansion in the use of green technologies can significantly lead to market penetration by sub-standard products that may fail to deliver the required results. More than often, because of product failure - due to substandard and poor quality products - convectional pumping system gain popularity. Consequently, the presence of substandard products with short service life, limits communities' ability to embed low cost technologies for sustainable water supply. The substandard systems act as market spoilers competing with high quality solar systems. When these substandard systems fail, the reputation of the standard solar system is affected among the community.

### **9.2.2. Poor service condition**

Poor service condition remains one of the key contributors to low technological base in rural and peri-urban water supply, constraining value adding activities in the provision of water services. Poor designs and the neglect of operation and maintenance components are factors have affected the continued functioning and sustainability of these water systems. Due to siltation of water pans and untimely repairs to equipment breakdown in solar and wind systems a key risk is the loss of the entire investment.

Lack of access to up-to date data and inadequate skills contribute to poor designs and constructions. Discussion with Bob Harries Ltd for example indicated that the wind mechanical systems were installed at a time when wind data was unavailable. The company had therefore to rely on their own experience. Neglect of attention to catchment conditions also reduces the life of water sources and infrastructure, particularly in the case of water pans. Only 4 out of the 25 water pans observed had a fence to restrict uncontrolled entry of livestock. Over grazing due to large number of animals on a unit of land results in the destruction of natural vegetation and reduces soil compaction around the water pan. This can result in erosion and hence sedimentation reducing the lifespan of the technology.

Weak regulation and oversight of design and implementers continues to impact on the level of service delivery and thus on the sustainability of rural and peri-urban water supply. It was found that most of the boreholes are drilled without hydrological authentication, which constitutes a major risk to the investment. In 2012, the Silango borehole in Baringo was developed by the Africa Inland Church (AIC) and was installed with both solar and wind pumping systems. After two month of operation, the submersible pump stopped functioning due to corrosion of the wetted surfaces because of high levels of salinity. With close proximity to an alternative source of water, the community abandoned the technology. The community reported that the water point was neglected due to the high maintenance cost linked to corrosion of the moving parts of the pump and the high salinity of the water. Furthermore, weak enforcement on borehole drilling has resulted in many low yielding borehole overseen by unqualified practitioners. Out of this kind of experiences World Vision Kenya was forced to develop an in-house team to design and conduct investigations for their supply system especially in the drilling of boreholes. The in-house process is very expensive for implementers although it has been successful in supporting planning, design, operation and maintenance of supply systems.

Traditionally, beneficiaries in rural and peri-urban areas become responsible for operating, maintaining and managing the water supply systems after a short period of training. The government and donors are installing systems ignoring the need to support the O&M component<sup>35</sup>. When unskilled people manage the O&M component low cost technologies face the risk of becoming dysfunctional and unsustainable. This gives a technology a bad reputation, convincing users that it cannot perform or that it has a short lifespan, as seen in the case of the Kijito mechanical wind pumps. There is a growing attitude that rural

#### Box 5: Ngaremara Water Pan: Poor planning and design

Ngaremara ward in Isiolo faced acute water scarcity causing the communities to walk long distance in search of water, especially for their livestock. High cases of water borne diseases and children missing school in search of water were reported. To mitigate these challenges, Action Aid developed the Ngaremara water pan with a capacity of 30,000m<sup>3</sup>(for Assets programme).

The water pan was intended to increase water supply in the area, especially to address water for livestock. However, the water pan has never stored water since it was developed. The following are some of observed challenges;

- i. Poor design
- ii. Poor siting for the water pan
- iii. Soil Infiltration and percolation

#### Lessons

- Site consideration is critical in enhancing sustainability of water pans
- Poor designs affect the ability of the technology to store water
- Soil erosion plays a major role in the siltation around the water pans. Therefore communities need to be trained on catchment conservation
- Neglect of catchment conditions reduces the life of water
- Early failure gives the technology a bad reputation



<sup>35</sup> 58% of the O&M cost is supported by the communities, while 2% is supported by donors and 19% by the government.

water supplies are low cost and therefore require low skills, which causes a lack of interest by high profile professionals. This stands in contrast to what is observed in the case of urban water supplies.

Dispersed water points and wide variety of technology brands appear to be more problematic in managing and supporting O&M services. Maintenance providers are confronted with the high unit costs associated with serving sparse populations, a low availability of spare parts, high risks associated with many discrete assets of unknown condition and poorly maintained roads. Establishment of adequate management mechanisms, monitoring and regulation is therefore essential. Improved mobile telephony and IT, performance-based operator contracts and 'pay-per use' approaches may prove to be effective ways to align commercial incentives with water point sustainability objectives.

### **9.2.3. Low financial capability**

Rural and peri-urban water supplies face huge challenges in accessing the capital needed for the development and improvement of supply systems. The challenge of constrained ability to develop and sustainably manage water supplies is more than often constrained by low financial capabilities, which are normally linked to the high investment and running cost of the technologies. Low financial capabilities in the rural and peri-urban water supplies are normally a result of inadequate revenue, fewer resources allocated to peri-urban and rural areas and weak or inexistent financial mechanisms to support the operation and maintenance of these systems.

The increase reliance on public funds either from the government or donors identified in rural and peri-urban water supplies limits the choice and capacity of technology significantly. The grant character of most water investments and the non-necessity of repayment have greatly contributed to weak or inexistent financing mechanism. Discussion with Bob Harris and Davis and Shirtliff indicate that water supply projects lack financial mechanism to take advantage of financing from Banks, since they do not meet the requirements conditions demanded by commercial lenders. The creditor confidence in the viability of water supply system as a viable business venture, capable of generating steady future revenue flows is found to be limited. The reason for this includes the insufficient capacity to collect, a lack of transparency and insufficient willingness and capability to pay.

Most of the technologies observed across the four counties were intended for less than 500 households. The limited number of people served by the technology does not create a platform to attract considerable revenues. This is also influenced by the lack of economic diversity due to the nature of community livelihoods that are largely not considered as income generating activities, which therefore limits the re-payment reliability of the systems. A small community base per technology limits the ability of the technology to attract financing, thus reducing its level of credit worthiness. Furthermore, community ownership may inhibit the possibility for public private partnerships (PPP) as community members believe that water management should be their responsibility. This is evidenced by responses from water users at the Wakalia Borehole in Embu managed by Grundfos, who indicated that they think that the company collects a lot of money from the point and that they feel exploited.



It was also found that the density of water supply points at a given location can negatively impact payment behaviour. This was the case in for example Kipsing market in Isiolo, where WSTF and Catholic Relief Services (CRS) had both installed water points. Here the water point installed by CRS was closed due to a disagreement on applicable charges. Finally, full recovery of capital costs through user fees was found to be rare, which means that widespread capital investment by private enterprises and entrepreneurs remains unlikely without external subsidies.

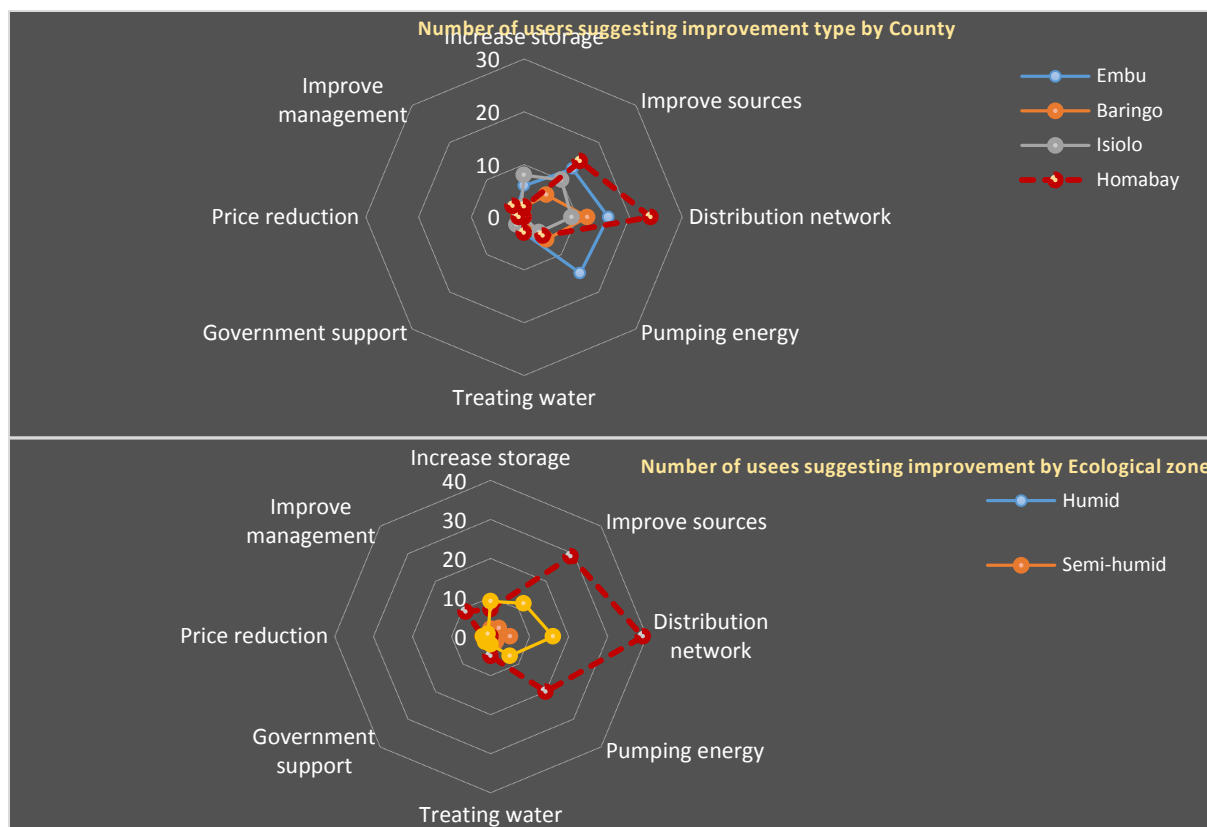
#### 9.2.4. Capital budget linked to community contributions

In all the counties and ecological areas there is an expressed demand for project designs that focus on poverty alleviation, reduce efforts and deliver benefits to beneficiaries, such as schools and clinics. A resource based approach is common for rural and peri-urban water supplies, especially in guiding the types of investments made. Water investments are dependent on the amount of resources available, therefore influencing the size and choice of investment. Rural and peri-urban communities are expected to contribute 20% of the total investments cost, which is not required in conventional urban water supplies. Limitation to meet their part of the contribution thus limits the size and choice of technology. When capital cost is higher compared to that of conventional water supply systems it represents an obstacle to embedding low cost technologies for sustainable water supply. Consequently, a demand responsive approach, which is an expression of demand and not an expression of investment value, should be adopted. Projects may differ in their specific objectives but they have several key features in common.

#### 9.2.5. Demand and preference of technology

There is an increasing recognition of the failure of supply driven water supply service provision. Water supply planners and implementers frequently focus on supplying minimum drinking water, with basic systems with consideration to ease of operations and maintenance. Moreover, the technology arrangement is assumed to work generally in rural areas and little attention is given to the structure or system that delivers water services. Typically, water projections do not anticipate water use and other variables that affect demand. This may result in a "gap" between anticipated and deployed levels of service. As a result, to achieve long-term sustainability, there is a need to focus on water supply arrangements and infrastructures which are responsive to the needs and preferences of the beneficiaries. These need to support users' livelihoods, by giving communities control and enable them to make informed decisions about technology and system service delivery. This enables ownership creation and strengthens the capacity of the communities to undertake other development activities

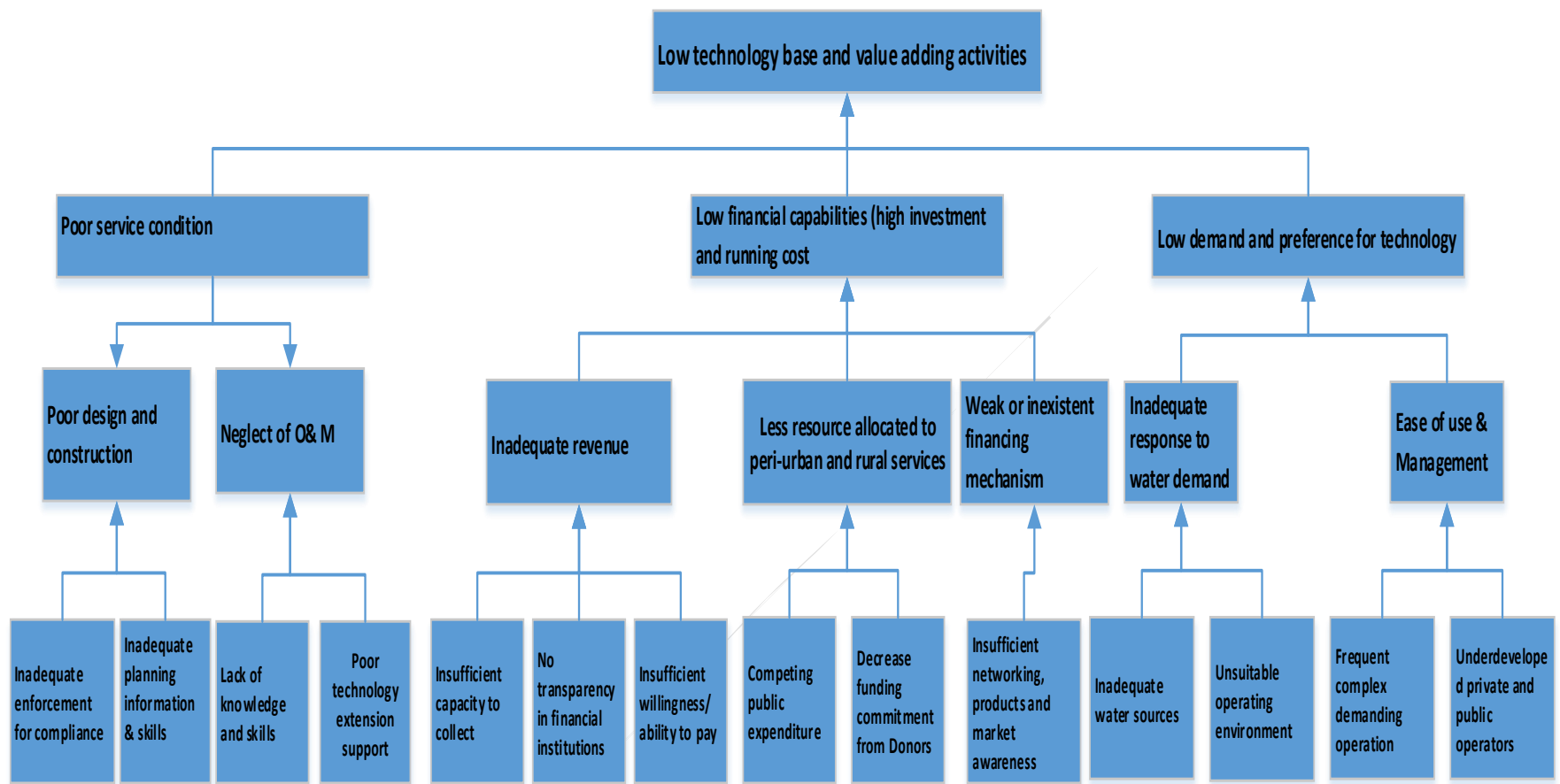
The analysis of suggestions by water user in Figure 37 compares improvements that would bring about higher consumer satisfaction. The development of the *distribution network* is a priority in all the four counties, followed by *improved sources* and *storage of water* and *pumping energy*. The extent to which the selected technologies achieve the improvements demanded by the users is critical to the value attached to the particular technologies and hence to their sustainability.



**Figure 37: Nature of water supplies improvement proposed by users**

### 9.3. Summary – technology risks and sustainability

- I. In realizing the importance of supplying water in rural and peri-urban areas, governments, local and international NGOs invest substantial capital to tackle the problem of low coverage and implement water projects.
- II. The construction of water supply systems by itself does not guarantee the elimination of all problems in rural and peri-urban areas. Functionality, utilization of technologies by the users and the resilience of these technologies are important aspects to be considered to achieve maximum benefits.
- III. For rural and peri-urban water supplies to be sustainable, it is necessary to understand the various risks and how these risks can be mitigated to ensure successful deployment. The sustainability of supply systems is affected by poor service, low financial mechanisms and low demand and specific preferences related to the selected technologies.



**Figure 38: Problem analysis of Low technology base**

## 10. Developing Green Solutions for water supply

*Beyond the fundamental benefits of lowering carbon emissions and increasing the climate resilience of communities, scaling up green technologies in the water sector has the potential to bring about significant economic, social and environmental benefits. This section highlights necessary actions and effort aimed to improve the quality and coverage of water supply services by implementing and developing the management of low cost green technology of water schemes by private operators, community and local government institutions.*

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### **10.1. Technology Funding and Financing Mechanism**

Continuing at the same level and pace of investments in water supply will not deliver the requisite volume and capital cost needed to develop sustainable water supplies. To address the issues of low financial capabilities due to the high investment and running costs of green technologies, it is necessary that the financial viability of rural and peri-urban water supplies is developed. The water sector will be required to pursue innovative transformations and reforms to enhance access to external capital sources. Efficient revenue collection and full recovery of operation and maintenance costs are necessary for enhancing financial serviceability of the rural and peri-urban water supply systems. Ensuring that water investments are meeting standards and are increasing service levels in term of quality/quantity and reliability/accessibility will influence water users' satisfaction levels and thus their willingness to pay. Box 6 depicts a model of how to enhance efficiency in revenue collection and cost recovery of operation and maintenance.

Additionally, to increase the bankability of water supply project, it is important that multiple uses of waters are taken into consideration. Taking a livelihood perspective and developing supply systems that provide explicitly for actual demands for both productive and domestic uses may have positive impacts on the financial viability of the system. Providing safe water for drinking and water for livestock and farming will lead to increase productivity and users will thus be able to sell their livestock and farm produce to cover outstanding debts for water investments.

### **10.2. Low Cost Green Technology Project Design**

Designing an appropriate project model and technology solution based on local contexts and needs, is critical to ensuring the sustainability of water supplies. Water investments should be developed in a manner that support national development goals of enhancing food security, creating job opportunities and reducing disaster risks, as described in the Vision 2030. The sizes of storage tanks in solar water pumping system should reflect the water demand for the community to support domestic and other productive uses. The water sector actors should not only consider water pans but also small storage structures that are applicable to wider ecological regions. Development of small storage structures will ensure moderate flows for upstream and downstream users, promote production upstream and contribute to groundwater recharge. To widen the benefits, the project design should be modelled to address the needs of the youths and support employment creation, as this group was found to be disproportionately affected

#### Box 6: Delivery Model

In 2015 Wakalia Borehole in Embu County was upgraded from a hand pump to a solar water pumping system by Grundfos through the Lifelink Projects in Kenya. The projects were developed as a means of enhancing long term sustainability of rural water supplies. Grundfos professional service team are handling the operation and maintenance of these technologies. 42 similar projects have been implemented in Kenya providing reliable access to water every day with an average of 364 operational days in a year. Grundfos signed a contract with the community management committee that would see the company run and manage the borehole for 10 years. During this period, Grundfos collects revenue from this point as a cost recovery measure for their injected capital cost.

Using the Wakalia borehole, the community are reprieved from the continuous struggle of operating, managing and maintaining water services. Since the installation of the solar water pumping system, the community around the Wakalia borehole reports to have experienced significant improvement in their living condition due to reliable water supply. "The system makes it easy for us to obtain water and cases of water borne diseases have gone down"- committee member. Some dissatisfaction with this delivery model was also expressed by community members, as they don't feel they benefit sufficiently from water service revenues. This may thus affect community ownership negatively.

In addition to the solar pumping system, Grundfos developed an automatic water dispenser with an integrated system for revenue collection and an online water management platform for full transparency and remote management. End-users can easily load credit onto water cards either through local water credit vendors or via mobile credit platforms, enabling fair and transparent transactions. Community members reported waiting long for card replacement, which limits their accessibility to the water point.

Despite some challenges this case serves as a model of service delivery where the high costs of investment are provided by a private operator, who in turn recovers costs from the revenue collected.

by poor water supplies in rural and peri-urban. Access to job opportunities by youth should be made a priority to strengthen and ensure the sustainability of water investments. Finally, it is important to understand that water users' aspiration goes beyond walking long distances to water point and lining up at water sources. It is therefore essential for project designs to be made attractive for the users and to ensure that water services support all water uses.

### 10.3. Business Management model

A least cost logic which focuses on investment only and leaves communities to operate and manage technologies does not offer lasting business benefits. Rethinking current community based management models is important to ensure the successful deployment of low cost technology for water supply. The main risk with the current management model is that it undermines a sustainable business case for rural water supply investments. Developing a business case for rural water supplies requires that the disperse nature of these system is taking into account. Clustering technology by type, size, geography or communities' social characteristics may provide an attractive approach. Effective clustering of disperse water supplies can provide economies of scale and pool risks in the operation and financial delivery of operation and maintenance services. As opposed to community based management that exposes the communities to unpredictable and volatile maintenance cost, the pooling of financial risks through cluster management may contribute to effective service delivery and increase the reliability of the technology. As mentioned, Davis and Shirliff indicated that they are working with PSI to supply solar system for lighting in 250 health centres. With this, Davis and Shirliff are able to secure a broad range of private services for managing operation and maintenance of technologies. This reduces the burden of technology management for the community, while at the same time providing expertise for increasing the efficiency and sustainability of the water supplies. Hence, clustering management creates an attractive platform for the establishment of a competitive environment for private operators.

The Grundfos Lifelink projects in Kenya have demonstrated that professional services are possible with current user charges. In this particular case, financial and technical sustainability is built on cluster operations of 42 water projects. By thinking in clusters, risks are mitigated by spreading services between rural and peri-urban areas, between low and high capacity sources and across different social set-ups. Consequently, the communities avoid the burden of managing and maintaining their water supply, while the operator is able to sustain a viable operational model. Ultimately, communities obtain reliable supply of water and are able to liberate their time to other engagements.

Kanyathiang water supply<sup>36</sup> in HomaBay County is an example of a delegated management model, which is an alternative to the community-based management model promoted since the 1970. This model has proven that contractual relationship between government authority and a private operator can guarantee a flow of services to the community and in the long run ensure the sustainability of the supply system. Kanyathiang was initiated in 2012 and operationalized in 2013 with help of lake Victoria south water services board and 8 other water supplies are under consideration for contracting to private operators. The procurement of operators is done on a competitive basis, with Kenyan firms and part of the staff employed must be from the host county. The scheme is running 11 kiosks and 8 schools with 19000 users. The county as the contracting authority is responsible for performance and owns the assets. The operator provides services as per the contract conditions. This separation of functions and responsibilities is at the core of a sustainable service.

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<sup>36</sup> *It is reported that soon after this study, Kanyathiang Water Supply has ceased operation due to high production cost involved and lack of salaries for its workers*

#### 10.4. Capacity Development and Raising Awareness

A key component to develop the market for rural and poor water supplies is awareness raising and the provision of professional support to demonstrate the viability and reliability of the technologies. Rethinking the assumption that beneficiary communities will after a short period of training be able to operate, maintain and manage the supply system on their own, is critical for reliable rural water supply business models. Capacity development should be undertaken in such a manner that it targets various stakeholders along the whole value chain, including technology suppliers, financial institutions and actors involved in the design and installation of solar water pumping systems, the operation and maintenance of the systems, as well actors responsible for policy and programme formulation.

Findings from the field study show that the key capacity development components needed to ensure continued functionality and sustainability of water supply schemes are the following:

- i. Development of support structure that addresses preventive and repair maintenance as for example the creation of professional associations (e.g. artisan associations)
- ii. Develop strong post implementation support at the community and private sector level to operationalize and monitor operation and maintenance.
- iii. Develop pilot programmes on green technologies to act as a bridge between basic knowledge generation and technological discovery on one hand and commercial and industrial adaptation on the other.

##### **Box 7: Financial Instruments and water demand creation for rural water supplies**

The ENA Irrigation multi-purpose Co-op Society project in Kyeni South of Embu was initiated in 1989 to improve water supplies for domestic and irrigation uses. The project aimed at providing water for irrigation for 278 farmers with acres ranging from 0.5 to 1 acre. With assistance from the District Water office, the community developed a multiple use project costing Ksh 46 Million. The project was financed by mix of Ksh 18 million grant from by African Development Bank and the Ksh 36 million loan facilitated through KFW to be repaid by the project beneficiaries in 25 years.

Food production in the area has increased drastically and surpluses are sold with clear impacts on community members' livelihood. The loan amount was fully repaid by the start of 2017 from revenue generated by agricultural activities

##### **Success factors**

Ring fencing of the water revenue, combining water for domestic use and other productive uses, professional and local government support, adaptable financing mechanisms

##### **Challenge**

#### 10.5. Policy, Legal and Regulatory Framework

The creation of steady and reliable regulation is key to unlocking investment potential and accelerates the deployment of green technology for water supply. Without the creation of a favourable regulatory and legal framework the adoption of green technologies for sustainable water supply will remain a small niche market. A key precondition for their development and deployment is to ensure that operators are

brought under regulation at the onset of the development of the system. Proper governance and regulation processes will facilitate the identification of problems at an early stage and assist in keeping water supply developments in check throughout the project cycle. A level playing field for green technologies vis-à-vis conventional options needs to be developed in order to build the market capacities of these technologies and ensure that they are cost competitive.

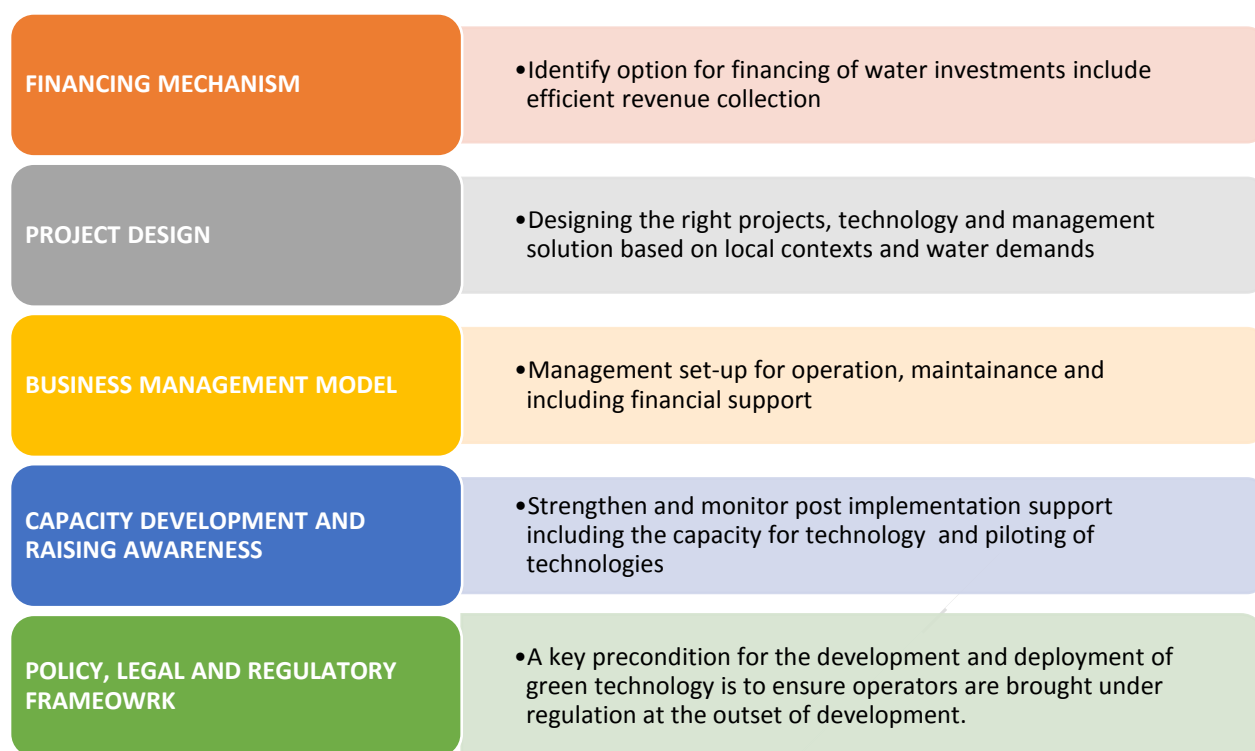
Furthermore, adequate standard and quality control need to be put in place to avoid the dumping of cheap and sub-optimum technologies in the market. To this end, policy makers should establish a solid, reliable and predictable environment which:

- Provides a level playing field between green and conventional technologies for water supply, addressing key issues such as unfavourable administrative requirements and systematic biases in financial regulation.
- Assures equality and transparency for all stakeholders in the market, while at the same time maintaining private partners' and investors' confidence.
- Builds community acceptance through constant communication on the benefit of green technology for sustainable water supply.
- Develops stable markets and operational frameworks to harness the full potential of green technology for effective and sustainable water supply

#### **10.6. Summary**

The Figure 39 below summarises the important consideration in designing a water supplies PPP





**Figure 39: Designing a holistic PPP Model**

## 11. Conclusion and Key Messages

Safe and adequate water is critical for improving health and livelihoods. Hundreds of technologies and configurations are available to deliver water services. Yet coverage and reliability of water supplies in rural and peri-urban remains low, due to high cost and low efficiency in operation, maintenance and poor attention to renewal of the existing infrastructure. This resulted in many of the systems becoming non-operational or to greater extent dysfunctional. Therefore, choosing the right technology for each community is an important task, which requires know-how, context specific understanding and attention to how communities are likely to deal with the real-life complexities of a water supply system.

Technology and innovation are major drivers of any serious momentum to address climate change and water poverty. While there are opportunities for new and retrofit technologies for water supply infrastructure, significant change will come about with the credentials of good technology. Therefore, assessing the applicability and viability of technologies is critical towards improving water supply, especially in underserved areas. The findings emanating from this study are aimed to inform the water sector in Kenya and most especially WSTF on how selected low cost technologies can be embedded, not only to guarantee sustainability of the water supply, but also for the possible deployment of these technologies, in a way which preserves investments and make them work more efficiently and for longer.

### 11.1. Key findings

The following outlines some of the key summaries emanating from the feasibility study:

- i. The majority of the technologies observed have a small capacity, with solar having a capacity of less than 5 kW, wind power less than 1 kW, and most water pans range between 10,000 and 30,000m<sup>3</sup> in volume 141 households share one borehole on average , while one water pan is shared by 162 households. Solar and water pans are widely in use but the functionality rate, especially for water pans, is very low. Both technologies show great potential for creating positive impacts for the target communities. The use of small wind turbines for water supply on the other hand is almost non-existent in the surveyed counties. There is limited information on small electric wind turbines and inadequate wind data to guide investment decisions. The poor performance of Kijito mechanical wind pumps diminished users' confidence in wind systems. Generally, the initial investment is high for wind systems because of the installation tower. Pilot and demonstration programs are necessary to enhance capacity building in order to bridge the gap between basic knowledge and technology discovery.
- ii. The uptake of the various types of energy sources for water pumping, including green energy, is higher in the semi-arid and arid areas, compared to humid to sub-humid zones. However there is an underlying perception that solar and wind are inferior technologies in comparison to grid electricity and generators, and only suited for small applications. There is a need to demonstrate that solar and wind technologies for water supply are durable and suited also for large engineered applications. Solar water pumping in particular has become very common in all the counties, yet this technology is relatively new to the market and therefore its full impact and sustainability is yet to be fully understood.
- iii. The majority of technologies primarily supplied water for domestic uses. The type and level of additional uses for water was found to vary across the counties and ecological zones; livestock and domestic use are dominant in Baringo, Homabay and Isiolo, whereas domestic and irrigation is prevalent in Embu. While the configuration and specific objectives of technology application differed in the four counties and ecological zones, they have several key features in common. These include the demand for projects that focus on poverty reduction and job creation, and of technologies which are be easy to use, operate and maintain. They should also deliver benefits to individuals, communities and other beneficiary groups such as schools and health centres. Focus on the development of multiple uses of water supply, which take into account a livelihood perspective, increases the scope of benefits and the prospects for long term sustainability of the technologies.
- iv. Water pans store water for limited periods after the rains and are therefore less dependable in prolonged dry weather conditions. Siltation and embankment failures are the major challenges affecting the functionality rate of the pans. However, if they are well designed, sited and properly managed, they show great potential for improving water supply in normal and extreme climate

conditions.

- v. In a few cases, utilisation of solar energy has enabled the creation of mini-grids serving water kiosks and individuals around the water source, as the examples of Kipsing in Isiolo County and Chepchamus in Baringo County have shown. This demonstrates the potential of solar PV systems to increase convenience and reduce the efforts required to collect water.
- vi. A high non-functionality rate of the selected technologies is influenced by poor sizing, siting and site investigation. Better skills and access to information are needed for improved planning, design, deployment and management of selected technologies.
- vii. Community based management remains the predominant management approach in all the four counties. Across all the counties, there is an underlying assumption that technology beneficiaries will operate, maintain and manage the system by themselves, after only a short period of training. For long term sustainability, the role of the community should be extended to identifying water demand and ensuring performance and should be less focused on the day to day management of supply systems.
- viii. The selected technologies promote inclusion, participation and spread of benefits to both women and men in all the counties. However, it was found that youth are rarely involved in water management, with the exception of two cases (Kipsing in Isiolo & Ruma in Homabay). This demonstrates the importance and potential of selected technology to engage and generate employment for youth.
- ix. A resource base approach has been used to guide water investment decisions, where communities are required to contribute to the capital cost. Community contribution may have unintended negative effects where communities (and especially project champions) take full ownership of the project. Furthermore, for large scale investments, the ability of community to afford the mandatory proportion (10-30%) is limited which may reduce the potential for scaling up the selected technologies. Moreover, the amount of financial support provided by WSTF (approx. Ksh 1-10 million) tends to limit technology viability and the impact of the investment.
- x. The survey observed that infrastructure deteriorates after project termination which underlines the imperative need to plan for operation and maintenance. Entrepreneurs figure less prominently in the management of dispersed water points. Dispersed water points and wide variation of brands appear to be problematic, restricting the opportunities to harness market forces to expand coverage in rural areas.
- xi. The ease of O&M and the high cost of maintaining diesel pumps and electricity systems are strong motivations in favour of solar PV. However, the seasonal fluctuations due occasional cloud cover reducing solar irradiation, as reported in all the four counties, affect the preference and choice of solar systems, as compared to conventional systems.

- xii. Post-construction maintenance (for equipment breakdown, spare parts, burst and leakages) undertaken by the local government was identified in all the counties. However, local level government support and market systems for spare parts and maintenance were found to very weak. Often community water supply managers do not know where to turn to for help when required.
- xiii. Individual pump mechanics are numerous and active in all the counties, although their maintenance service approach involves a number of weaknesses. Many contract-based arrangements have been introduced as possible alternatives for water point management. However few of these have been tested in the field, and for those that have, the results have been mixed. There is also a need for a greater recognition that intermediaries have an essential role, not only in the design and construction, but also in post-construction activities.
- xiv. The ease of operation and maintenance is central to the sustainability of technologies and must therefore be given careful consideration in their design. While it is generally known that operation and maintenance issues are location-specific, it should be emphasized that peri-urban and rural projects differ fundamentally in their complexity. Community managed projects are based on a basic and undemanding system, which tends to restrict technology choices to those that can be operated and maintained within the community without or with minimal external intervention. In peri-urban areas, users are often migrants and therefore less bound to the same locality, which also means that there is little social cohesion, compared to for example in rural areas. This presents a key challenge to long-term operation and maintenance arrangements.
- xv. Users in rural and peri-urban areas are disproportionately disadvantaged. In contrast to their counterparts in urban areas, beneficiaries in rural and peri-urban areas are required to contribute to capital investments and manage supply system on a voluntary basis. In addition, they have to pay for water services at rates which are in many cases much higher than for their urban counterparts. It is rare that rural areas receive subsidy for O&M, which is common for several urban water supplies.
- xvi. Climate risk in water supplies is addressed by default but not exclusively. There is no evidence of provision or guidelines that account for increasing severity and erratic patterns of weather, nor are there dedicated units and funding set-up to spearhead climate change adaptation and mitigation for the water sector.
- xvii. There are many programmes spreading awareness and products, which potentially will create demand for extended use of technology and critical market segments for maintenance and management services

## **11.2. Recommendations**

To successfully support the uptake of the selected technologies the following needs to be considered;

- a. **Social groups and long-term sustainability of markets need to be taken into account when considering financial instruments** The choice of financial support for low cost technology should be comprehensive to ensure long term sustainability of the market. A combination of incentives such as long term credit, grants and tax exemptions are indispensable in making these solutions more affordable, while at the same time leaving room for market development. The youth should be considered in the investment benefits, as they are considered to be dynamic, forward looking and in the best position to spearhead and benefit from innovative solutions.
- b. **Consideration of climate change impacts for the water sector should be made explicit.** Explicit inclusion of climate change issues in the water sector should be in a manner that set out the mandate of spearheading efforts in climate change adaptation and mitigation. In addition, a comprehensive implementation framework and funding structure to ensure that investments achieve both water services improvement, while at the same time addressing climate vulnerability and risks across different agro-ecological regions.
- c. **Ease of operation and technology maintenance** is central to its sustainability and high recognition must be accorded to this fact from the planning and design stages. External assistance to operation and maintenance in rural and low-income urban areas creates opportunities to harness market forces for the selected technologies and subsequently expand coverage.
- d. **Support commercialisation of rural and peri-urban water services.** Managing clustered technology by geography, technology type or size in order to establish a viable business scale is essential. Output based maintenance and performance based assistance should be considered when embedding low cost technologies for sustainable water supply. In some cases, subsidies, guarantees and suitable financing structures for both suppliers/manufacturers and consumers are needed for productive uses of water and to speed up technology uptake in underserved areas. Commercialization of rural and peri-urban water supplies can be enhanced through developing methods that promote efficiency in revenue collection.
- e. **Water demand creation:** Current domestic water consumption of 60-120 liters per HH per day is low and may thus not be possible for operators to break even. At the same time, basic access to water is protected and there only so much that can be charged for water use. Therefore, there is a need for holistic planning, which includes other water uses to create demand for water. Planners and implementers have a role to influence productive uses of water which simultaneously improves livelihoods, create youth employment and raise water sale revenue necessary for water service provision viability
- f. **Focus on post implementation support** is necessary to ensure that private operators have access to after-sales and extension support for routine operation and maintenance. Professional support both in term of ensuring sufficient human and financial capacity should be an integral part of programme design for rural and peri-urban water supplies.
- g. **Capacity development** for both artisans and professionals involved in the design is essential to create a critical mass of skills specialised in rural and peri-urban engineering. Pilot and demonstration programs, especially with respect to small wind turbine, are necessary to enhance capacity building in order to bridge the gap between basic knowledge and technology discovery.

- h. **Monitor technology performance and gather data.** The evidence base on low cost technologies for sustainable water supply is limited. Availability of data is therefore important for establishing a business case for intervention and development of delivery models for different scales of water supply. Players involved in piloting these technologies need to put in place sufficient data gathering mechanisms to build upon the knowledge base of post-deployment impacts of low cost green technologies solutions. This is particularly the case for wind pumping systems.
- i. **Rethink community management approaches in water supply services.** The community based system of water services management is not working adequately. Community cluster management of technology is suggested as an alternative by which communities play a key role in defining priority water uses and the application of technology, while also being involved in monitoring the performance of operators. At the same time, community cluster management of technology provides economies of scale and contributes to pool risks in the operation and financial delivery of maintenance services. For small population centres, community cluster will create a customer base that supports private sector management of mini-grid operations.
- j. **Small piped schemes and cluster technology are viable entry points for private sector involvement** in the management of dispersed water technology points in rural areas. It is therefore crucial to create a facilitative environment, which is conducive to the application of small-scale decentralized solar, small wind turbines and water pans for water supply. This may require standardisation or a limited range of technology options, parts, designs and construction methods. In the long-term, this will entail lower skill levels and repetitive action, which will help to improve quality. This is seen as way to encourage local manufacture and stockist because the limited range reduces start-up costs, increases sales and reduces the risk of dead stock.

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## Annex 1: List All Key Partners And Stakeholders

LIST ALL KEY PARTNERS AND STAKEHOLDERS				
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## Annex 2: Pictorial Description



**Photo 3:** water abstraction using bucket in Homabay. Animal and humans access indiscriminately raising risk of water contamination. Common scenario is evidenced in the other three counties



**Photo 3:** Siltation remain the key challenge affecting the functionality and durability of water pans



**Photo 3:** Poor design and siting of water pans limits the technology ability to retain water throughout the dry season observed in Isiolo







**Photo 4:** Mechanical wind pumps. Most of the systems have been replaced by solar systems



**Photo 5:** Hybrid system solar and small wind turbine in Baringo County. The system is not functional since the submersible pump has corroded due to high water salinity





**Photo 9:** PV array installed to replaced mechanical wind system in Lambwe, Homabay



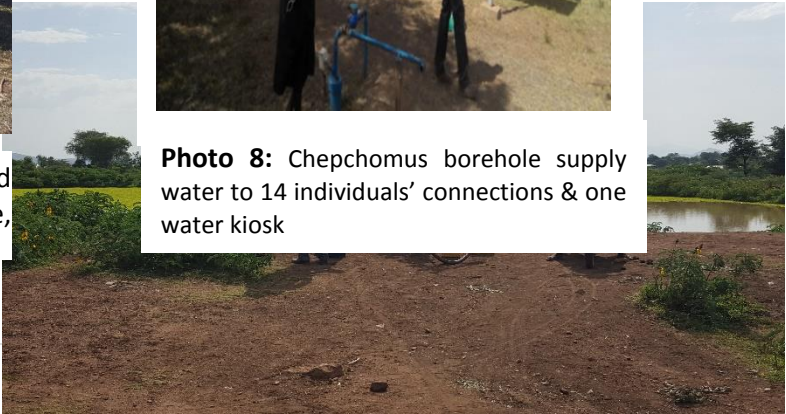
**Photo 8:** Chepchomus borehole supply water to 14 individuals' connections & one water kiosk



**Photo 7:** Losambumbur borehole in Baringo supporting small scale farming and livestock use



**Photo 10:** Woman collecting water from surface water eds growing on the water surface



**Photo SEQ photo \\* ARAan.** Notice the ween on motorcycle fetching water for sales. This is prevalent in Homabay and



**Photo 12: Small irrigated garden near solar powered water point in Homabay**



**Photo 11: Greenhouses in Lambwe supported by solar PV systems**



### Annex 3: Key Informant synthesis report

Key informants interviews	
Introduction	<p>This report presents the summaries of the various key messages emanating from discussions with key informants. The key informants were drawn from varied institutions namely; the county government of Baringo, Embu, Isiolo and Homabay, Upper Tana Catchment Natural Resources Management Project –IFAD, World Vision Kenya, Red Cross society of Kenya, Caritas, Water Resources Authority, Ministry of Water and Irrigation representing National Government, Kenya Rapid, Water services providers; Eldamaravine Water and Sewerage Company, Isiolo Water and Sewerage Company and Homabay Water and Sewerage Company and other community water committees namely; Garbatulla North Water supply Committee in Isiolo County and Muiya water supply water committee in Baringo.</p>
Technologies used for Water Pumping and storage of Water	<ul style="list-style-type: none"> <li>- There is use of divergent pumping systems namely; electricity, diesel, solar and wind is evident across the four counties with small dams, earth dams, water pan and sand dams being used for storage. The use of small dams was reported in the humid areas of Baringo and Embu County with water pans, earth dams and sand dams being reported to be developed in the semiarid to arid areas. The use of wind water systems is not common in all the counties, with the few existing wind mechanical systems not being functional.</li> <li>- The use of solar PV for pumping water is adopted in all the four counties with new installations being established and rehabilitation of other convectional systems namely; diesel and hand pumps. The costs of solar investments are dependent with the capacity of solar required against water demand. The ease and low cost in operation and maintenance of solar systems is considered to be the main factor for rehabilitating diesels and hand pumps with solar PV. The cost of installing solar systems is very high but its running costs are low compared other conventional systems. Electricity and fuel subsidies are issued by the county governments to the communities.</li> <li>- Water Pans have been developed in all the counties especially in the semiarid and arid ecological zones. Water pans are primarily used for livestock and farming and high cases of salinity but in instances of lack of alternative sources they are used for domestic purposes.</li> </ul>
Common technologies Vs. Water Demand	<ul style="list-style-type: none"> <li>- Common technologies used in all the four counties do not adequately meet water demand. Water has primarily addressed domestic uses although not fully but demand for water for livestock and irrigation is not adequately met.</li> <li>- Water Pan sustain water throughout the dry season with high cases of siltation being reported. The water quality of water pans is poor.</li> <li>- Solar systems are well addressing water for domestic uses. Solar system work for eight hours due to changes of solar irradiation in different time in a day.</li> </ul>
Performance of common technologies in different season and climate extremes	<ul style="list-style-type: none"> <li>- Surface water in Baringo and Isiolo counties is not reliable throughout the year with the use of borehole observed both in dry and wet seasons.</li> <li>- Water Pan are considered to be good small storage structures for addressing livestock demand especially during climate extremes periods High evaporation during dry season affects the ability of water pans to retain water throughout the dry season. Performance of</li> </ul>



	<p>water pans is normally limited if water demand exceed technology capacity.</p> <ul style="list-style-type: none"> <li>- The performance of solar water pumping system is affected in different seasons. During the dry season due to high sunlight intensity the system output is high compared to rainy season when the sunlight intensity is low.</li> </ul>
Potential of selected green technologies in addressing water supply issues	<ul style="list-style-type: none"> <li>- The green technology displays great potential for addressing the prevailing water supply challenges. The challenges of poor construction, poor siting and limited hydrological authentication limit the potential of the systems.</li> <li>- The high running costs for conventional systems increases solar PV system potential in enhancing accessibility of water. The use of solar system have contributed to reduction of water borne diseases</li> <li>- Post implementing support cannot be overlooked in enhancing the potential of the selected green technologies.</li> </ul>
challenges of ensuring Adequate, Reliable and Affordable water supply	<ul style="list-style-type: none"> <li>- Water scarcity and erratic rainfalls</li> <li>- High cost of water supply emanating from high cost of operating and maintaining technologies especially for conventional systems.</li> <li>- Heavy reliance on fuel and electricity subsidies by communities</li> <li>- Poor technical support by technology intermediaries affecting system functionality rate</li> <li>- Long distances to water sources; low water coverage</li> <li>- High water salinity</li> <li>- Limited funds for water investments</li> <li>- Dilapidated water networks</li> </ul>
source finance for construction, operation and maintenance	<ul style="list-style-type: none"> <li>- The source of construction is pooled from varied sources namely, national and county government, NGOs and the community</li> <li>- The community contribute 10% of the capital cost either in case or in-kind (labour and construction materials)</li> <li>- The O&amp;M cost is mainly derived from revenue collected</li> </ul>
Management model and capacity that will support adoption and deployment of selected technologies	<ul style="list-style-type: none"> <li>- Constant monitor of technology performance</li> <li>- Post implementation support</li> <li>- Training of community on management</li> <li>- Institutionalise on rural water supply systems</li> <li>- Enhanced Community participation in the entire project cycle</li> </ul>
PPP for improved water supply	<ul style="list-style-type: none"> <li>- Management of water resources is not income generating entity and therefore pulling in the private sectors in the management is not possible.</li> <li>- Developing of entrepreneurial processes towards the management of water is currently being adopted through 'livelihood component in management of water resources</li> <li>- concrete plan to engage the private sector is important to ensure that communities are not over exploited by private sector interested in profit making</li> </ul>
Do beneficiaries match up initial pan?	<ul style="list-style-type: none"> <li>- Usually beneficiaries do not match up initial plan. Nonetheless, <ul style="list-style-type: none"> <li>o water quality has been improved</li> <li>o reduced distances to water points</li> <li>o availability of water for productive gains</li> </ul> </li> </ul>



## Annex 4: Stakeholders synthesis report

Technology suppliers report synthesis		
Introduction	<p>This report presents the summaries of the various key messages emanating from discussions from various technology suppliers. Technology suppliers play an important role in the deployment of the selected technology as their role in the whole value chain cannot be neglected. The views in this report were collected from private organizations namely; Epi-centre, Go solar, Davis &amp; Shirliff, Bob Harries Ltd and Centre for Alternative Technology, government institutions such as National Drought Management Authority, Donors such as World Bank and Non-Governmental Organization e.g World Vision.</p>	
Cost of Technology	<p>The cost of the technology varies with water demand.</p> <ul style="list-style-type: none"> <li>- For solar water pumping system, the current cost is 100 Ksh / watt</li> <li>- The cost of solar installation is directly related to the amount of yield. For instance Ksh 170,000 for 10m<sup>3</sup>/day, 1 to 2 million for 50m<sup>3</sup>/day and 10 million shillings for 600m<sup>3</sup>/day. This prices include the cost of developing a borehole and solar installation</li> <li>- For water pans, the cost largely varies with the size. For a well-designed water pan of a capacity of 50, 000m<sup>3</sup> the cost is 14 million</li> <li>-</li> </ul>	
Operation and maintenance	<p>Operation and maintenance plays a key role in ensuring functionality and sustainability of water supplies. The following are some of the highlight on O&amp;M by the technology supplies;</p> <ul style="list-style-type: none"> <li>- Solar systems are almost 100% free of maintenance. Expect for occasional cleaning of panel, in any case dust accumulated on panel which usually results to only 10% loss of power output Beneficiaries are normally trained on operation and maintenance before project commissioning</li> <li>- The solar systems are fixed with GSM system that assists in remote monitoring of the technology. Remotely monitor PV systems is important in reducing time and costs associated with site visits</li> <li>- Davis &amp; Shirliff have services centres in some areas across the country to support in operation and maintenance</li> <li>- For the wind system, lack of O&amp;M component has resulted in technology being dysfunctional or deterioration of the system useful life. Lack of post implementation support by the government has led to abandonment of the technology by the community. To mitigate this, Bob Harries are encouraging their new clients to sign up maintenance contracts of up to five years.</li> <li>- The maintenance of water pans is still a great challenge affecting the sustainability of pans. Many of the pans are not de-silted and within few years after their commissioning the pans dries up</li> </ul>	
Factors affecting the performance of the technologies	<p>Several factors are known to affect the performance of the selected technologies. These factors are;</p> <ul style="list-style-type: none"> <li>- The quality of the boreholes. Siltation of the borehole causes clogging on the pump whereas salinity of water causes corrosion on the wetted parts of the pumps</li> </ul>	

	<ul style="list-style-type: none"> <li>- Poor design have resulted to drying up and silting of the water pans</li> </ul>
Key challenges	<p>Wind systems</p> <ul style="list-style-type: none"> <li>- Most of the technology suppliers have not be involved in development of wind systems due to the challenges of maintenance</li> <li>- Lack of skills on wind pump maintenance resulting to abandonment of the system over time</li> <li>- For bigger communities the wind system output is low not sufficient to meet the required demand</li> <li>- Implementer's considered wind to lack a more sustainable solution to community projects</li> <li>- High cost of installation</li> <li>- With the cost of solar reducing, windmill uptake has been reducing over years</li> <li>- wind water pumping system trend is not foreseeable due to high cost and lack of technical skills and solar system are taking over the market</li> </ul> <p>Solar Systems</p> <ul style="list-style-type: none"> <li>- The output of solar affected by seasonal fluctuation a case which is not experienced in the use of grid electricity and diesel generators therefore affecting the preference and choice of technology</li> <li>- Vandalism of solar system and therefore security checks are incorporated as part of installation cost</li> </ul> <p>Water Pans</p> <ul style="list-style-type: none"> <li>- Heavy burden of maintaining the pans is left for communities that lack this capacity therefore sustainability not guaranteed.</li> <li>- Erratic rainfalls is a challenge in collection of runoff water</li> <li>- poor management of the systems</li> <li>- Poor water quality ( high faecal components, contamination by fertilizers)</li> <li>- Siltation and increased environmental degradation around the pan due to human activities</li> <li>- High rates of evaporation, infiltration and percolation</li> </ul> <p>Commufnity based management of rural water supplies are not sustainable. It is important that water supplies are institutionalised.</p>
PPP Model comments	<ul style="list-style-type: none"> <li>- Water is a public good. Engaging the private sector in the management of water supply may result to overcharging of water with an aim of making money</li> <li>- High cases of unwillingness to pay for water is evident in rural water supplies therefore may impact on the private operator mandate of making profit ability to generate profits</li> <li>- WVI has engaged private operators in managing their water supply systems. The community signs service contract with the operator. It is important that mechanisms are put in place to ensure community benefits are realised vis-a-vis the operator is making profits</li> </ul>

## Annex 5: survey tools

### i. Technology point manager/caretaker survey questionnaire

#### Section 1: General Information

1. Collect GPS coordinates (*automatic using mobile application*)
2. Name of the interviewer
3. County:
4. Sub-county:
5. Administrative Location, Ecological Zone:
6. Photograph of the technology:
7. Year of installation /construction:
8. Weather conditions during survey
9. Period since last rainfall

#### Section 2: Administrative Information

10. Specific technology point
  - a. Water Point (**go to 11**)
  - b. Others (specify) (**go to 13**)
11. Type of water sources of water? (*select all which applies*)
  - a. Borehole, depth (if known)
  - b. Shallow wells, depth (if known)
  - c. Water Pan
  - d. Small dam
  - e. River
  - f. Others.....
12. How many months in the year is water available
  - a. Never
  - b. 1 month
  - c. 2 months
  - d. 3 months
  - e. 3-6 months
  - f. 6-9 months
  - g. 9-12 months
  - h. Throughout

If not available throughout the year, why

13. Please specify energy source and application:
  - c. Solar powered (**go to 14**)
  - d. Wind powered (**go to 15**)
  - e. Diesel
  - f. Hand pump (**go to 1817**)
  - g. Grid electricity (**go to 1817**)
  - h. Gravity (**go to 1817**)
14. How many cells are used for the solar system?
15. Specify the wind energy?
  - a. Wind-electrical
  - b. Wind- mechanical

16. What is the height of the installed windmill? (metres)
17. Is water placed in a storage tank before distribution?
- Yes
  - No
  - If yes, what is the size of storage, (m<sup>3</sup>)
18. Who owns the technology?
- Community
  - Government
  - CSO
  - Private Company
  - Individual
  - Others.....
19. Who owns the land on which the technology stands?
- Community
  - Individual
  - Private Institution.....
  - Public institution.....
  - Others.....
20. Type of uses (**Select all that applies**)
- Domestic (**go to 21**)
  - Institutional (**go to 21 [ii]**)
  - Livestock (**go to 22 23**)
  - Farming (**go to 24**)
  - Industries
  - Others.....
- 21.
- How many households are served by this technology point?
    - 0-50
    - 50-100
    - 100-150
    - 150-200
    - > 200; specify
  - How many users are there in the institution?
22. What is the average number of individuals in a household? .....
23. How many animal are served by this technology point?
- Cattle.....
  - Sheep & Goat.....
  - Donkey.....
  - Camel.....
24. How many farmers are serviced by this technology point?
- 0-50
  - 50-100
  - 100-150

- d. 150-200
- e. > 200; specify

25. What is the average size of irrigated land for each farmer?

## Section 2: Financial Analysis

26. What is the source of construction finance? (**Select all that applies and percentage Contributed**)

- a. Donor
- b. Government
- c. Community
- d. Private
- e. Others.....

27. What is the approximate construction cost?

28. What is the source of operating and maintenance finance? (**Select all that applies and percentage Contributed**)

- a. Donor
- b. Government
- c. Community
- d. Private
- e. Revenue
- f. Others.....

29. What are the main challenges experienced while using this technology? (**Select all that applies**)

- a. Equipment breakdown
- b. Complex/difficult to operate
- c. Lack of spare parts
- d. Low revenues collection
- e. others (specify)

30. Who operates the technology?

31. Is the caretaker/ operator skilled?

- a. Yes
- b. No
- c. **If Yes**, What is his qualification?

32. Is there anyone who provides training to caretaker/ operator?

- a. Government
- b. technology supplier
- c. NGO
- d. Others (specify)

33. What are the normal operation costs of the technology?

- a. Fuel cost.....
- b. Operator salary.....
- c. Others (specify)....

34. How often is does the system undergo maintenance?

- i. Bi yearly
- ii. Quarterly
- iii. Yearly

- iv. > Year (specify).....
35. How long does it take for repairs to be addressed?
- i. 1-3 days
  - ii. 4-6 days
  - iii. 1 week
  - iv. 2 Month
  - v. > 2 month specify.....
36. Which components of the technology fail most often?
37. What is the approximate cost of maintenance per month.....
38. is any improvement that's needed to improve performance of technology
39. Who does the maintenance?
- a. County government
  - b. Local technician
  - c. External technician
  - d. Technology supplier
  - e. Others.....
40. Does the technology have
- a. Operation plan (Y/N)
  - b. Maintenance plan (Y/N)
41. How much is charged for the water?
- e. Domestic (per m<sup>3</sup>).....
  - f. Cattle.....
  - g. Sheep & Goat.....
  - h. Donkey.....
  - i. Camel.....
42. What is average amount collected in a month.....

### Section 3: Technical Analysis

43. Does the technology have the capacity to handle the water needs in the community?
- a. Yes
  - b. No
- If no, what is the problem?
44. What is the capacity / size of the technology
- a. If water storage.....m<sup>3</sup>
  - b. if borehole, yield .....m<sup>3</sup>/hour
  - c. If powered ..... ☐ watts ☐ kVA
45. On average, how many hours does it work in a day?.....
46. Does it work differently during different times of the day ?
- a. Yes
  - b. No



If yes, explain.....

47. Does it work differently during different times/seasons of the year?

- c. Yes
- d. No

If yes, explain.....

48. Do you think the technology is reliable?

- a. Yes
- b. No

If no, why.....

49. Consumer distance to **this** water technology point?

- a. What is the distance covered by the furthest consumer of this water Technology? (km)
- b. How much time does it take the furthest user to reach this technology point (Minutes)

50. Average distance to **alternative** water sources?

- c. How far is the alternative water sources from the nearest source (km)
- d. How much time does it take to reach the alternative water source (minutes)

#### Section 4: Social Analysis

51. Which technology do you think is best to enhance water supply in the area? (max three)

52. Are the users satisfied with the technology?

- a) Very satisfied b) Satisfied c) Not satisfied d) Very Dissatisfied (if not, why?)

53. What are some of the benefits accrued by the users of this technology

54. In your perception, what are the most important water related issues in this area?

55. Are you aware if there are water uses constrained by the amount of water available from this technology?

#### Section 5: Water Quality

56. Is the water good for purposes (drinking, livestock, irrigation)

57. Related to 56, what is the impact of the water quality on users?

### iii. USER INTERVIEW QUESTIONNAIRE

#### Instructions to participants:

*The Water Services Trust Fund is undertaking field survey on the potential of water pan, solar and wind energy to improve water service level in the underserved urban and rural areas across the country.*

*The survey will determine among others;*

- i. *Prevalence of selected technology in different parts of the country,*
- ii. *If technologies currently in use provide adequate water supply in different climate zones and seasons, otherwise the potential of the selected technology to overcome critical challenges facing water supply*
- iii. *Arrangement that's best placed to make selected technology easily available and minimise operation failures.*

*Feedback from this study will greatly contribute to the social aspect of this assessment. Your participation will be appreciated and confidentiality will be observed with respect to your feedback.*

**Part I Personal and General Data**

1. Date and time interview (automatic)
2. GPS coordinate (Automatic)
3. County, Ward and administrative location, Ecological zone
4. Name of the interviewer
5. What is your name? (Optional) \_\_\_\_\_
6. What is your telephone number and email address (if available)? .....
7. What is your gender? M      F    ☐    ☐
8. What is your occupation?
9. How many members are there in your household?

**Part II Existence of water sources and functionality**

10. Which is the common source(s) of your water supply:
  - i. Wet season
  - ii. Dry season

**(Provide selection list - tick more than one source where necessary)**

  - a) Piped network
  - b) Borehole
  - c) Water Pan
  - d) Sand Dams
  - e) Shallow well
  - f) Rivers
  - g) Private rainwater tank , specify construction material
  - h) Others (Specify).....)
11. From the answer above, what method is used for abstracting water in your nearest source of water supply?
  - a. Solar water pumping system
  - b. wind pumping system
  - c. Diesel pump
  - d. Hand Pump
  - e. Grid electricity
  - f. Gravity
  - g. None
  - h. Others.....(specify)
12. How is water obtained from this technology used? **(Select all that applies)**
  - g. Domestic
  - h. Livestock
  - i. Poultry and fishing rearing
  - j. Farming
  - k. Commercial (specify)
  - l. Others.....
13. What is the current status of your main water sources in terms of functionality?
  - a.) Functional (go to 19)
  - b.) Non functional

c.) Temporarily down

d.) Don't know

If not functional or temporarily down, explain

14. How many months in the year is water available at the nearest water technology point

a. Never

b. 1 month

c. 2 months

d. 3 months

e. 3-6 months

f. 6-9 months

g. 9-12 months

h. Throughout

15. On average, how many hours in a day is technology at your nearest water source working?

16. Does the technology at your nearest point work differently in different time of day?

e. Yes

f. No

If yes, explain.....

17. Does the technology work differently in different times/seasons of the year?

g. Yes

h. No

If yes, explain.....

18. Do you think the technology is use at your nearest water source is reliable?

• Yes

• No

If no, why.....

19. In your own opinion, what are the main challenges observed in provision of water using this technology.....

### Part III Technology Point Operation and Management

20. Who is responsible for managing this technology?

a) County Government

b) NGOs/CBOs

c) Individual

d) private

e) None

f) Others..... (Specify)

21. If yes, how many times in a week are they present at the water sources?

a) Once a week ☐ b) Twice a week ☐ c) Three times and above ☐

d) Never present ☐ e) Do not know ☐

22. Is there water manager/caretaker resident in this community?

a) Yes ☐

b) No ☐

23. Usually, what is the gender of the water manager/caretaker?

a) Mostly males ☐

b) Mostly females ☐

24. Have conflicts over water arisen within the community since the technology was implemented?

If yes which ones and how was it resolved?

25. From the above mentioned technologies, in your opinion what improvement should be introduced to ensure water supply?

#### Part IV Level Community Contribution towards O&M

26. How much do you pay for the water fetched?

27. Do people in your community contribute towards the following water services?

**You may tick more than one where necessary**

a) Initial investment cost Yes ☐ No ☐

b) Operation and maintenance Yes ☐ No ☐

c) Do not contribute at all ☐

d) Do not know ☐

28. Are you satisfied with how the caretakers respond to water and technology problems?

**Please indicate by ticking, whether you are; 1 = extremely satisfied, 2 = satisfied, 3 = dissatisfied or 4 = extremely dissatisfied, using a scale given between 1-4, with 4 being the highest score**

1 ☐ 2 ☐ 3 ☐ 4 ☐

If not satisfied, why

#### Part V Level of support by government/NGO agencies

29. Is there any kind of support offered to your community or water management committee by the following agencies?

a) National Government agencies Yes ☐ No ☐

b) County government Yes ☐ No ☐

c) CDF Yes ☐ No ☐

d) NGO Yes ☐ No ☐

e) Private contractors Yes ☐ No ☐

f) Others (Specify).....

30. Do you know what kind of support is provided by the above organizations?

31. If yes, how satisfied are you with the level of support to ensure provision and sustainability of water supply by these agencies?

**Please indicate by ticking, whether you are; 1 = extremely satisfied, 2 = satisfied, 3 = dissatisfied or 4 = extremely dissatisfied, using a scale given between 1-4, with 4 being the highest score**

a). County government 1 ☐ 2 ☐ 3 ☐ 4 ☐

b). Sub County Local government 1 ☐ 2 ☐ 3 ☐ 4 ☐

c). NGOs 1 ☐ 2 ☐ 3 ☐ 4 ☐

d). Private contractors 1 ☐ 2 ☐ 3 ☐ 4 ☐

e). Others (Specify)..... 1 ☐ 2 ☐ 3 ☐ 4 ☐

**Part Vi Impact of Technology To the user**

32. Are you satisfied with the technology being used

Yes ☐ No ☐

33. If no, why?.....

34. How can you rate the water technology easiness in use?

**Please indicate by ticking, whether you are; 1 = extremely satisfied, 2 = satisfied, 3 = dissatisfied or 4 = extremely dissatisfied, using a scale given between 1-4, with 4 being the highest score**

1 ☐ 2 ☐ 3 ☐ 4 ☐

35. Average distance/time to the **nearest** water point?

e. How far is nearest water source from your home (km)

f. How much time does it take to reach the nearest water source (minutes)

36. Average distance/time to the **alternative** water sources?

g. How far is the nearest alternative water sources (km)

h. How much time does it take to reach the nearest alternative water source (minutes)

37. How much time do you spend daily to fetch water?

38. Who in your household is typically responsible for fetching water?

39. Has the technology assisted you to obtain water easily?

Yes ☐ No ☐

If no, how so?.....

40. In your opinion, what could be done to improve water supply in this area?

a).....

b).....

c).....

41. Is the water good for consumption?

a. Yes

b. No

42. Is the water obtained from this technology enough for your needs?

a. Yes

b. No

43.

a. How much water do you collect everyday?

b. How much water do you require for all your daily needs?

**Part VI: Interviewer Observation Remarks**

1. The technology point e.g. the state of water pan. solar and wind installation **(please allow for space to type in)**

2. The physical environment of the site e.g. the environmental hygiene and sanitation **(please allow for space to type in)**

3. The protection systems e.g. the fencing among others **(please allow for space to type in)**

4. Any other thing that will be of interest to the team **(please allow for space to type in)**

## ii. Questions guide for semi-structured interview

### (Key Informants & Focus Group Discussions)

Name of interviewee or group:

Organization:

Level of responsibility:

Place of interview

Date:

#### A. Policy and Top Management

*(Line ministries, County Executives, National Agencies)*

1. Which technologies are commonly used for storage and pumping water supplies and which factors mostly influence technology choice?

*(Guide to interviewer: How important are these factors, are water pan, solar and wind energy ranked among the most prevalent technologies? How many have been constructed in the last 1-year and by who?)*

2. Do the common technologies adequately address water demand and development priorities  
*(Guide to interviewer: Which are the priority water needs, are benefits equitably distributed, what quality is required for priority water uses, what is the pattern of water demand)*

3. What is the performance of common water technologies (and water pans, solar and small wind turbines, if any) in different seasons and climate extremes  
*(Guide to interviewer: do the current technologies [and selected low-cost technologies, if available] adequately meet water demand, throughout the year, is the quality adequate for priority water uses, what is the pattern of water demand vis-à-vis the technology capacity)*

4. What is the potential contribution of green technologies, specifically water pans, solar and wind energy in addressing water supply challenges  
*(Guide to interviewer: Is there a systematic effort to incorporate green technologies in water supplies or it happens at random, who are the key actors; suppliers, standard and regulation, capacity building, O&M)*

5. How do you engage private sector in the improvement of water supply?  
*(Guide to interviewer: Is there a strategy to engage private sector participation in development and management of water supplies?)*

#### B. Implementation and Middle Level Management

*(Project and Water Service Managers, Technology suppliers, civil society)*

1. Which are the main challenges towards ensuring water supply is adequate, reliable and affordable across the year in the county/country?

*(Guide to interviewer: Are efficiency gap known and articulated in the management plans? is there potential for water pans, solar and wind energy to address these challenges?)*

2. What is the main source finances for construction, operation and maintenance of water supply?  
*(Guide to interviewer: How is the cost infrastructure development met? Is cost recovery mechanism in place? Is revenue collected sufficient to maintain water supplies? Is the cost affordable to the users?)*
3. What is the potential contribution of water pans, solar and wind energy in addressing cost and technical challenges  
  
*(Guide to interviewer: Is there a strategy for greening water supply? if green technology has been implemented what is the experience, are water pan, solar and wind energy sources among the preferred technologies)*
4. Which management model and capacity will support adoption and deployment of water pans, solar and small wind energy technologies for sustainable water supplies?  
  
*(Guide to interviewer: What knowledge, technology management and capacity gaps require attention for deployment of water pans, wind and solar energy?)*
5. Do the current beneficiaries match up the initial plan?  
*(Guide to interviewer: in cases where water pan, solar and wind technology is implemented, what were the envisaged benefits at the beginning, were the target benefits achieved, if exceed or less than expected, why?)*

### Focus Group Discussion Guide

1. Has this technology improved the amount and quality of water available round the year?  
  
*(Guide to interviewer: How is water availability situation before the technology and now?)*
2. What are the impacts brought about by the implementation of this technology? Who has benefited the most?  
  
*(Guide to interviewer: What difference has the technology made in the way people relate, derive income, spend time and money and educate, is there change in priorities activities, are there any businesses that have emerged since the technology was installed?, does the project benefits men and women in different ways? if yes how, are benefits the same for different income and age group if yes how and why? )*
3. Is the technology easy to manage and do you think the benefits will continue for long time? If no, why not?  
  
*(Guide to interviewer: Who operates the technology, has any modification been made to ease operations, what happens when technology breakdown? Do the beneficiaries consider this is best technology for the situation?)*
4. Have conflicts arisen in the community over water since the technology was implemented? If yes which one and how are they being resolved?  
  
*(Guide to interviewer: is there section of community dissatisfied with the technology? could this be as result siting, cost of water, exclusion of important water needs, inadequate water supplied by the technology or management model?)*

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